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ABSTRACT

This paper is a summary of research on the perceptual and memory processes related to reading, their developmental progress in children, and the reading abilities in adults. Reported among the results of the various studies are the following: (1) developmental changes in reading after second grade primarily improve speed of coding, (2) reading appears to depend on visual analysis of units at least as large as single words once word decoding skills have been acquired and developed in practice, (3) children appear to develop automatic word recognition processes as they learn to read rather than later as they develop fluency, (4) college students can perform visual search tasks and read single words for some comprehension at presentation rates of up to 1,200 words per minute, and (5) similarities are present in the reading processes of college students and late primary grade children. (AEA)

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FINAL REPORT

Grant No. G-77-0010

An Information-processing Approach to the Development of Reading for Comprehension

Technical Report Number NIE-R80-1

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Abstract

This paper is a summary of the research on reading and learning to read performed at the University of Kansas pursuant to a grant from the National Institute of Education (Grant No. G-77-0010, 1977-1979). Studies were conducted with both children and adults participating in a variety of tasks designed to analyze performance on skills related to reading as well as on normal reading for comprehension tasks. Initial work investigating visual perception of words and wordlike letter strings demonstrated that most children rapidly acquire encoding skills as they learn to read. By the end of the first grade, children apparently can recognize common words more efficiently than other letter strings. Additionally, by the end of second grade, children typically show effective use of their knowledge of orthographic structure to facilitate recognition of unfamiliar letter strings. Later developmental changes primarily improve speed of decoding; no qualitative changes in processes were observed.

Studies using visual search for different types of targets while reading prose passages demonstrated that adults can search more rapidly for specific word targets than for smaller units such as syllables or letters or for targets defined in terms of meaning. This pattern of results was also obtained for 8 and 10 year-old children, and all groups performed word search while reading with no apparent loss in reading speed or comprehension. Thus, once word decoding skills have been acquired and developed in practice, reading appears to depend on visual analysis of units at least as large as single words.

Paralleling perceptual development in children are skills related to rapid and automatic access of word meanings. Our studies have found that, like adults, children in the fourth grade recognize conceptual equivalence of pictures and their names and can compare them equally well in memory. Even earlier, children show interference effects on the Stroop task, in which they are to name the color of ink in which the name of a different color is perinted. From our work using this task, children appear to develop automatic word recognition processes as they learn to read rather than later as they develop fluency.

A final series of studies involves reading text presented as a rapid sequence of single words located at a common area on a computer-controlled CRT display. We have found that college students can perform visual search tasks and read for some comprehension at presentation rates of up to 1200 words per minute. We are now seeking to determine the optimal means of presenting text via computer to allow rapid reading for comprehension.

In sum, we have reported the results of a number of studies of perceptual and memorial processes related to reading and their developmental progress in children. The results have yielded insights into the process of decoding words and accessing their meanings by children as they learn to read. Our studies of reading abilities in adults have indicated that there are many similarities in the reading processes of college students and late

primary grade children. The differences that exist are presumably due to more rapid decoding processes, more effective allocation of attention and other processing capacities, and the ability to use a larger store of relevant information in memory to facilitate comprehension and integration processes. It is to these latter abilities that we will direct future research efforts in gaining an understanding of how adults read for comprehension and how children acquire this competence.

Introduction

Learning to read involves acquiring a few new skills specific to reading and adapting many other previously learned cognitive skills to the reading process. Some children learn to read quickly and efficiently. At any grade level, one finds children who are highly skilled given their level of instruction. They are soon identified and are frequently termed "skilled" or "above grade level readers." Other children have greater difficulty with reading; regardless of the label, such as "less skilled," applied to them, their reading skills are below expectations given the amount of instruction they have had.

Our objective in this research program is to identify basic cognitive components of reading that differentiate between beginning and advanced readers and between skilled and less-skilled readers. We assume that the identification of such differences is essential to a descriptive model of reading skill development and, subsequently, to a prescriptive model for reading instruction (cf., Glaser & Resnick, 1972).

The approach is largely comparative and developmental; we compare adults and children at different age, grade, and/or reading levels in order to determine the course of skill acquisition. We concentrate on three phases of the reading process: word perception and recognition, lexical access, and comprehension of simple text. We hold that the components of the reading process are interrelated in practice, and that the interaction is dynamic, changing as skill level increases and as the complexity of the task changes. This assumption is the reason we investigate the word recognition process, a unique and basic component of reading, as part of each phase of our research program.

The beginning reader typically has already acquired linguistic and conceptual knowledge relevant for understanding oral language and for interpreting visual experiences. In order to learn to read, the beginning reader must learn a new language code, which is based primarily on the spatial configurations of the written language rather than on the temporal relations of the speech code. Much of beginning reading instruction is therefore directed towards activities unique to processing the visual code. Beginning students of reading must be taught the elements of the code, the left-to-right ordering of these letters and words in text, and their more-or-less arbitrary relationships to spoken language. Thus, the teaching of reading is focused largely on the acquisition of basic visual recognition and decoding skills. The ultimate purpose of this phase of reading instruction is the rapid and essentially automatic identification of words, a skill assumed vital to comprehending written text.

Rapid word identification is an effective component skill in reading in that it allows limited attentional capacity to be shifted from decoding processes and maintaining phonemic codes to accessing lexical and semantic information about words. In fact, when word recognition becomes an automatic process (LaBerge & Samuels, 1974), it might be unnecessary during reading to divert attention from the processing of meaning to the recognition of individual letters and words. The significance of rapid word recognition to reading for comprehension has been further emphasized by Venezky and Massaro (in press) who claim that it is the only important skill unique to reading.

Despite the fact that rapid word identification is recognized as an important component of the reading process, little is known about the development of this skill. Some of the research reported here was designed to investigate the acquisition of rapid word recognition, to identify the factors underlying that skill, and to contribute ultimately a model of rapid word recognition and its developmental sequences. Such a model should eventually provide a basis for designing effective methods for instruction.

The second area of research makes use of the Stroop color-word interference paradigm to study the development of automatic processes. Naming the color of a set of letters is markedly slowed if the letters themselves spell the name of a different color (see Dyer, 1972, for a review). Presumably the delay occurs because the word, generated automatically, interferes with the color name, which is the correct response (e.g., Posner & Snyder, 1975). This research paradigm is used to explore the development of automatic processing in reading (e.g., Guttentag & Haith, 1978; Rosinski, 1977). If the words must be processed to the level of meaning for interference to occur, then the amount of interference produced by various words should be related to the relative speed with which their meanings are accessed. Developmental studies of Stroop interference and related phenomena are used to trace automatic processes involved in recognizing the meanings of individual words and to relate these skills to measures of reading for comprehension.

The third area of reasearch is aimed at designing new methods of studying reading for comprehension directly. Some of this work is patterned after similar studies of sentence and paragraph reading (e.g., Ball, Wood, & Smith, 1975; Kintsch, 1974), in which sentences or paragraphs are visually presented and are to be read for comprehension. Some include pre-specified targets that the subjects are to detect while reading. By varying the level of the target from surface letter or syllable patterns to words or semantic categories, we attempt to determine what target levels are most closely related to the level of processing used during normal reading. The speed and accuracy with which targets are found, and the relative success of answering immediate and delayed questions about paragraph contents are used as converging measures in our studies of comprehension.

A final area of research involves the use of rapid, serial presentations of single words and short phrases on a computer-controlled CRT terminal. Initial studies have shown that people can accurately perceive letter strings presented one at a time at rates greater than 600 items per minute. Additional experiments have been used to mimic the visual experience of reading under controlled conditions; i.e., several words are presented to central vision for 200-300 msec. and are followed by successive words from a text presented to the same locus at a constant rate. Our research has shown that reading for comprehension can be done normally using such serial presentation methods, and we are currently attempting to determine the parameters of visual presentations that maximize readability for rapidly-presented text.

The research presented in this report was supported, totally or in part, by NIE grant G-77-0010; it is also part of a continuing effort. We completed 11 experiments during this grant period, and these have been reported in 5 publications to date with 4 submitted or in preparation. The lines of research initiated during this grant period are now being continued and supported by a second NIE grant.

The research is summarized in the body of this report. Where work has been published the summary is relatively brief and the publication version is contained in the appendix. Research that is not yet published is presented in greater detail in the body of the text. We have also attempted to interrelate and integrate the separate studies as appropriate. A final summary and discussion conclude the report.

I. WORD RECOGNITION AND VISUAL SEARCH

The Development of Visual Information Processing Skills Related to Reading

James F. Juola, Margaret Schadler, Robert J. Chabot,
and Mark W. McCaughey
(Full report in Journal of Experimental Child Psychology,
1978, 25, 459-476.)

Many experiments have demonstrated that literate adults can use their knowledge of English orthography or their familiarity with specific words and common letter clusters to facilitate word recognition processes. Although word superiority effects in visual perception have not always been found, adults generally perceive words more accurately than other letter strings when they are briefly presented (Estes, 1975; Massaro, 1975; Reicher, 1969; Smith & Spoehr, 1974). Similarly, response times are usually shorter in visual search and same-different comparison tasks when words rather than nonword letter strings are displayed (e.g., Henderson, 1977; Krueger, 1970, 1975; Taylor, Miller, & Juola, 1977). Word superiority effects develop rapidly. Krueger, Keen, and Rublevich (1974) reported that 9-10 year-olds' search times for letters were shorter for word displays than for nonwords, and this difference was in the same proportion for children and for college students. Other experiments have indicated that children in the second and third grades are aware of structural regularities in English orthography, although it is not clear whether they are able to use this knowledge to facilitate rapid word recognition (Doehring, 1976; Lefton & Spragins, 1974; Lefton, Spragins, & Byrnes, 1973). It is clear that, from the beginning years of reading instruction, children have some knowledge of English spelling patterns based on what they have read as well as on what they can intuit from known correspondences between phonology and orthography. Our questions are related to the kind of orthographic information acquired early in learning to read and how this knowledge comes to be used in reading and recognizing words. We are concerned with the development of rapid word recognition processes and other visual information processing skills presumably related to reading. We use a visual search task because reliable word superiority effects have been found in other studies using this method (e.g., Gilford & Juola, 1976; Krueger, 1970; Krueger et al., 1974), and because it seems to be a task that can profitably be used with children who have not yet learned to read.

Method

The subjects were groups of 20 college students, fourth graders, second graders, and kindergarten children. The task consisted of the visual presentation of a single target letter followed by a three-, four-, or five-letter display. The subjects were instructed to make a positive response if the target letter were included in the display and a negative response otherwise. The displays were either common words, orthographically regular and pronounceable pseudowords, or orthographically irregular and unpronounceable nonwords. The stimuli were photoenlarged so that they would approximate normal reading size when viewed in a tachistoscope. Two different target letters were selected for each display string such that one matched one of the letters in the string and was used on positive trials, and the other did not match any of the letters in the string and was used on negative trials. The sequence for each trial was the target letter, a mask, then the display string, which remained on until the subject responded by pressing the "yes" or "no" button. Response times were from the onset of the display field until a response was made.

Results

Separate analyses of variance using a within-subjects design were performed on each group's response time data. For all grade levels, responses were faster on positive than on negative trials, and response times increased with display size. Multiple comparisons made separately for each grade level indicated that there were no significant differences between response times for words and pseudowords for any subject group. For college students, response times for words were significantly faster than those for nonwords, with response times for pseudowords midway between them. For fourth and second graders, mean response times for both words and pseudowords were significantly faster than those for nonwords. For the kindergarten group there were no significant differences in response times among words, pseudowords, and nonwords. The negative slope was almost exactly twice the positive slope for the response time by display size functions for the kindergarten subjects, but the differences between the negative and positive slope values decreased with grade level such that the two slopes were approximately equal for the college students.

Discussion

College students, fourth grade, and second grade children apparently process visually presented letter strings in much the same way. Whereas response times decreased with grade level, the search process used by subjects in these groups appeared to be quite similar. They also were sensitive in similar ways to the types of materials being searched, as responses were generally faster for words and orthographically regular pseudowords than for irregular nonword letter strings. In contrast, the kindergarten children apparently used a different search strategy and were insensitive to manipulations of orthographic structure in the display. We observed a facilitative effect of orthographic regularity on visual search performance for children at about the same time that previous research indicated that they are able to discriminate between orthographically regular and irregular letter strings (Golinkoff, Note 1; Rosinski & Wheeler, 1972).

The fact that there were no differences among the display types for kindergarten subjects is consistent with the hypothesis that they encoded and processed the display strings as individual letters. Beginning and prereaders presumably have little if any knowledge of standard orthography or familiarity with commonly-occurring letter cluster units to use as a basis of word perception. That the shift in visual search strategy and the effects of orthographic regularity on perception should appear within the same grade level is not unexpected; familiarity with the visual language code gained through reading should logically facilitate both encoding and search processes. It is somewhat surprising, however, to observe the rapidity with which such familiarity is acquired. Although the rate at which visual information is processed continues to increase, the cognitive processes involved in rapidly recognizing words and searching them for specific letters appear to be functionally equivalent for adults and for children who have been reading only about two years.

Whole-word Units are Used Before Orthographic Knowledge in Perceptual Development

Mark W. McCaughey, James F. Juola, Margaret Schadler
and Nicklas J. Ward

Many children acquire information about the structure of written language before they enter school (e.g., Lavine, 1977; Marchbanks & Levine, 1965; Pick, Unze, Brownell, Drozdal, & Hopmann, 1978). Knowledge of orthographic sturcture can be used to facilitate word recognition processes in children as early as the second (Juola, Schadler, Chabot, & McCaughey, 1978) and third grades (Stanovich, West, & Pollack, 1978). Subsequent changes in word perception skills seem to be largely quantitative (Krueger, Keen, & Rublevich, 1974), thus the major developments in word recognition skills occur rapidly and early in the course of learning to read.

Our main concern was the development of word perception skills and visual search strategies of beginning readers. In an earlier study (Juola, et al., 1978), we found that children as young as five years could reliably and accurately perform a visual search task in which they had to decide whether or not a given target letter appeared in a subsequent string of three to five letters. Kindergarten children, most of whom could not read, were found to search through words, pronounceable pseudowords, and unpronounceable nonwords at the same rates and with no differences in errors. They also used a slower, apparently self-terminating search strategy as opposed to the more rapid and seemingly exhaustive search process used by older children and adults. Second and fourth graders found the embedded target letter more rapidly when the displays were common words and pronounceable pseudowords than when they were orthographically irregular nonwords. The older children appeared to use the same search strategy as the adults, and their data were similar to those for adults in all ways except overall speed.

The differences in word perception and visual search skills between kindergarten children and second grade and older children merit further investigation. The rapid transition from the context-insensitive performance by the kindergarten children to the use of orthographic information by the second graders is evidence for the early acquisition and use of perceptual knowledge about common words and English spelling rules. To determine whether information about specific words or general orthographic knowledge is at the root of these transitions, we investigated the performance of pre-second grade children in the visual search task. If early reading experience results in the acquisition and use of orthographic information such as commonly-occurring spelling patterns, then advantages for both words and pseudowords over nonwords in visual search performance should emerge at the same time. Alternatively, if information about specific words is used in the recognition process before more general orthographic rules have utility, then words should show an advantage over both pseudowords and nonwords for children during the transitional period. Differences in performance for pseudowords and nonwords should then become apparent only later, after a significantly greater amount of orthographic information has been acquired. The present study was designed to test these alternative hypotheses.

Method

Participants. Twenty-three children were tested prior to entering the second grade and one child was tested during the third week of school. The mean age of the children was 7 years-4 months (range: 6-9 to 7-11). The children were chosen from lists provided by the Lawrence, Kansas, Unified School District. Each child received $3.00 for his/her participation. Twenty-four University of Kansas students served as a comparison group and received research credit in an introductory psychology course. All participants were native English speakers with normal or corrected to normal vision.

Materials and apparatus. Ninety words were selected from the Kučera and Francis (1967) word lists with the constraints that they contain one syllable and no repeated letters. The selection included equal numbers of three-, four-, and five-letter words with mean frequencies of occurrence approximately equated across word length (mean frequency = 275/million). Anagrams of the words were used to make 90 pronounceable pseusowords and 90 unpronounceable nonwords.[1]

The stimuli were typed with an IBM Selectric typewriter in lowercase Courier typeface. The stimuli were then photo-enlarged (2x) and mounted onto 15.2 cm by 22.9 cm white cards for presentation in an Iconix three-field tachistoscope. The letter strings measured 0.5 cm high and varied in length from 1.5 cm to 2.5 cm depending on the number of letters in the display. These measures correspond to horizontal visual angles of .88 to 1.46 degrees when viewed in the tachistoscope. Additional stimulus cards were made for the individual target letters and for a pattern mask containing a 4 x 8 matrix of overlapping, uppercase Xs and Os.

Two different target letters were selected for each display. One occurred in the letter-string display and was used on positive trials; the other did not appear in the string and was used on negative trials. The positive target letters were chosen to balance their serial locations in the strings across display type and length conditions. The two target letters for each display were used for alternate participants such that each display was used equally often on positive and negative trials overall, and half the trials were positive and half negative in each cell of the design for all participants.

Procedure. The children were tested individually during three 45-minute daily sessions. The college students were tested in two 45-minute sessions. For the children, one experimenter manually changed the stimulus cards for each trial, and a second experimenter gave verbal instructions to the child and recorded response times and error data. Only one experimenter worked with the college students.

In order to insure that the children fully understood the task, we used a training sequence in which the task was first introduced without the tachistoscope, then the tachistoscope was added for a set of practice trials. The children were first taught to press a "yes' and a "no" button rapidly in response to verbal commands.[2] In the next phase, the experimenter held up three cards consecutively; the first and third each contained a single letter, and the second card was the pattern mask. The children were told to press the yes button if the letter on the first card matched that on the third card and to press the no button if they did not match. Finally, the card containing three-, four-, and five-letter strings was introduced as the third card in the three-card sequence. Each child was given 12 practice trials using the tachistoscope, and these were repeated if they made more than three errors.

All participants were presented with 270 experimental trials divided into nine blocks of 30 trials each. Three of these blocks contained common words, three contained pseudowords, and three contained nonwords. The experimental sequence of the trial blocks was counterbalanced across participants. Before each block, the participants were told what type of display to expect. Eighteen practice trials using materials similar to the experimental stimuli preceded the first block of each display type in a test session; thereafter, nine practice trials preceded each block. Each trial began with a verbal "ready" signal from the experimenter. The sequence for each trial began with the participants viewing a single target letter for 1500 msec, the pattern mask for 500 msec, and then a three-, four-, or five-letter display. The display terminated when the participant pressed one of the response buttons. Response times were measured from display onset until the button was pressed. All participants were told and frequently reminded to respond as quickly and as accurately as possible.

Post-test questionnaire. In order to determine whether the participants could discriminate between the words and pseudowords, they were each presented with one of two lists of randomly-ordered words and pseudowords (30 of each) sampled from the experimental stimuli. The experimenter pointed to each letter string and asked the participant to say "yes" if it were a word and "no" if it were not. The responses were recorded by the experimenter.

Results

The mean times for correct responses, standard deviations, and mean error rates for all cells of the design are presented in Table 1.[3] All factors produced significant main effects in an analysis of variance on the response time data. That is, responses were slower for the pre-second grade children than for adults, $\underline{F}$ (1, 46) = 132.3, $\underline{p} < .001$, response times increased with the number of display letters, $\underline{F}$ (2, 92) = 95.4, $\underline{p} < .001$, and positive responses were faster than negative responses, $\underline{F}$ (1, 46) = 32.3, $\underline{p} < .001$. Furthermore, the overall analysis showed that there were

Table 1

Mean response times (in msec), standard deviations of response times, and mean error percentages for pre-second grade children and college student adults for three-, four-, and five-letter displays of words, pseudowords, and nonwords on positive (+) and negative (-) trials.

		3 letters			4 letters			5 letters		
		mean	S.D.	%E	mean	S.D.	%E	mean	S.D.	%E
Pre-second Grade Children										
Words	+	1410	377	6.0	1499	396	6.5	1628	478	7.6
	-	1511	476	7.6	1588	394	5.4	1901	596	8.1
Pseudowords	+	1506	474	8.0	1519	391	7.7	1720	518	9.3
	-	1559	453	6.2	1683	516	6.0	1904	712	5.5
Nonwords	+	1475	447	9.0	1504	433	6.8	1655	427	4.9
	-	1591	571	5.0	1688	450	8.5	1979	644	4.5
College Students										
Words	+	514	49	3.0	534	47	2.5	566	57	5.3
	-	558	59	2.2	576	46	1.4	605	67	0.6
Pseudowords	+	522	40	2.0	528	48	2.0	575	50	3.9
	-	563	51	1.9	580	54	0.6	612	64	2.5
Nonwords	+	541	45	2.5	544	45	3.0	582	41	3.0
	-	565	45	1.9	587	52	1.1	638	54	1.9

significant differences among the response times for words, pseudowords, and nonwords, F (2, 92) = 4.8, $p < .01$. As can be observed in Table 1, the effect of display size was greater for pre-second graders than for adults, F (2, 92) = 36.5, $p < .001$. The children also showed a larger difference between positive and negative response times than adults, F (1, 46) = 11.3, $p < .002$. In addition, significant effects were found for the interaction of response type by display size, F (2, 92) = 8.4, $p < .001$ and for the grade level by response type by display size interaction, F (2, 92) = 7.35, $p < .001$. These interactions reflect the facts that response times increase more rapidly with increasing set size for children than for the adults, and further, the increases are parallel for the adult data for positive and negative responses, whereas the response type functions diverge for children. Although there are some non-linearities in the data, the results can be summarized by noting that the best-fitting linear functions relating mean positive and negative response times to display size were approximately parallel for the college students (slopes equal about 25 msec and 28 msec per letter, respectively), whereas for the children, the negative function has nearly twice the slope (187 msec per letter) of the positive function (102 msec per letter).

Separate analyses of variance were performed on the mean response time data for college students and pre-second graders. The results of these analyses are shown in Table 2. For both groups of participants, response times were significantly faster on positive than on negative trials, and mean times increased with display size. The main effect of display type was also significant. All three factors interacted marginally for the adults, whereas only the previously discussed display size by response type interaction was significant in the children's data.

The childrens' and adults' mean response times for each display type shown in Table 3. Multiple comparisons revealed that the college students' mean response times for words and pseudowords were not significantly different from one another, t (1256) = 1.5, $p < .1$, and they both resulted in faster response times than nonwords. (For pseudowords, t (1256) = 4.9, $p < .001$; for words, t (1256) = 6.5, $p < .001$). Further, 19 of the 24 adults showed the advantage for the combined word-pseudoword mean response time over the mean for nonwords. The word-pesudoword advantage is the same result that we found in an earlier study for second and fourth grade children and adults (Juola, et al., 1978). The pre-second graders in the present study showed a different pattern; words were searched faster than pseudowords t (1256) = 4.7, $p < .001$, and pseudowords and nonwords produced equivalent response times, t = 0.0. Seventeen of the 24 children showed the advantage for words over the two other display types.

Response times on positive trials were found to depend somewhat on the serial position of the target letter in the display, although there were no significant differences in the details of these functions for words, pseudowords, and nonwords. Separate analyses of the data for each display size within grade level showed significant effects only for five-letter items presented to adults, F (4, 115) = 2.5, $p < .044$. In general, response times were equal across serial positions except for a slight trend to respond more

Table 2

Significant Main Effects and Interactions in the Response Time Analyses for the Two Participant Groups

College Students	df	F	< p
Response type	1,23	106.4	.001
Display type	2,46	5.5	.007
Display size	2,46	109.7	.001
Response type X Display type X Display size	4,92	2.8	.031
Pre-second Graders			
Response type	1,23	20.7	.001
Display type	2,46	3.5	.038
Display size	2,46	55.1	.001
Response type X Display size	2,46	8.1	.001

Table 3

Mean Response Times and Mean Standard Deviations in Msec for Word, Pseudoword, and Nonword Displays for Each Grade Level

Grade Level	Display Type					
	Words		Pseudowords		Nonwords	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Pre-second	1590	485	1649	509	1649	536
College	559	119	563	128	576	133

rapidly to target letters in the leftmost position.

An analysis of the error data shown in Table 1 showed only two significant effects. Pre-second grade children made more errors than the college students, $\underline{F}$ (1, 46) = 28.2, $\underline{p} < .001$, and more errors were made on positive trials (misses) than on negative trials (false alarms), $\underline{F}$ (1, 46) = 12.6, $\underline{p} < .001$.

In the recognition test, both college students and children consistently recognized the words; they respectively identified 29.8 and 26.1 of the 30 words in the sample as words. The children showed a greater tendency to misclassify the pseudowords, however, falsely identifying 11.8 of them, on the average, as words as opposed to a mean false alarm rate of 1.0 out of 30 for the adults.

During April of the first grade year, the Stanford Reading Achievement Test was administered to our population of sutdents at their respective schools. Results were available for 21 of the 24 participants. The Stanford Reading Achievement Test consists of four subtests and two composite measures. We computed correlations between these six reading scores and two search rate measures: (1) mean response times for word displays, and (2) mean response time differences between words and the combination of pseudowords and nonwords. In general, children with higher test scores responded more rapidly to words than did children with lower scores, and those with higher scores also tended to show a greater difference in their response times between words and pseudowords. However, none of the individual correlations achieved significance, ranging from -.20 to -.42 for correlations with mean times for words and from .08 to .27 for correlations with the amount of the word advantage (with $\underline{df} = 20$, an $\underline{r}$ of .42 is required for the .05 significance level).

Discussion

The present data are consistent with our previously reported results (Juola, et al., 1978) and with the expectation that the performance of the pre-second grade children would be transitional between prereaders and more skilled readers. Despite the fact that the stimuli were blocked according to display type in the present study and randomly ordered in our other study, the college students' data were very similar in these two studies, and the pre-second graders' mean response times were intermediate between those of our previous kindergarten and second grade groups. The pre-second graders appeared to use the same search strategy as the kindergarteners, one that differs from that used by more skilled readers. The relationship among response times for words, pseudowords, and nonwords evidenced by these pre-second graders is unique, differing both from those for prereaders and for more skilled readers. Each of these results will be discussed in more detail.

For both the present data from pre-second grade children and those of the kindergarten group in our previous study, the ratio of negative to positive slopes for the response time by display size function was nearly 2:1.[4] This ratio, consistent with a serial and self-terminating search strategy (Sternberg, 1966, 1975), is in sharp contrast to the nearly equal values of the slopes for college students in the present study and for second grade and older groups of participants in other studies. The latter ratio is more consistent with a serial and exhaustive search strategy (but see also Juola, et al., 1978; Townsend, 1971, 1972, 1974; Townsend & Roos, 1973).

The mean response time for the pre-second graders (1629 msec) is about halfway between those we reported previously for kindergarten (2114 msec) and second grade children (1275 msec) despite the fact that the pre-second graders differed in both age and grade level from the second graders by only a few months and from the kindergartners by 1 1/2 years. The difference in mean response times for the kindergarten and pre-second grade groups is probably due to a combination of maturational factors and reading-related experiences such as familiarity with the alphabet and common words. In contrast, the difference in response times between the pre-second and second grade groups seems to be primarily due to the latter group's shift to a more efficient search strategy.

The results of the present study as well as those from our earlier work (Gilford & Juola, 1976; Juola et al., 1978) are consistent with a model of visual search performance that assumes that total response time is equal to the sum of the times necessary for encoding the display, searching that encoded representation for the target letter, deciding if a match had been found during the search, and executing the appropriate response. The pre-second grade children appeared to use the same search strategy for all three display types; display type did not interact with either response type or display size. Analysis of the target serial position data also showed no indication that different search strategies were used for different display types. Thus, the word advantage seems to be due to the speed with which pre-second grade children can execute the first or encoding stage for words relative to pseudowords and nonwords.

Apparently then, the encoding process changes significantly in the early phases of reading skill development. Whereas kindergarten children showed no performance differences across the display types, the present pre-second grade group showed an advantage for words over both pseudowords and nonwords, which were responded to equivalently. Older children and adults have shown a consistent, but sometimes statistically unreliable, advantage for words over pseudowords and have produced significantly faster response times for pseudowords than nonwords. These results suggest that recognition of familiar words precedes the development of the ability to utilize smaller units of orthographic information. Although adults and older children seem to use orthographic information to aid word and pseudoword perception, pre-second grade children apparently have not yet constructed these rules from their knowledge of specific words and individual letters such that they can facilitate rapid word perception. Apparently children accumulate a substantial reading vocabulary before they acquire enough information about the regularities in standard English spelling to facilitate rapid processing of regular but unfamiliar letter configurations.

Visual Search for Letters in Intact and Mixed-case Words and Nonwords

Timothy McNamara, Nicklas Ward, and James F. Juola
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1978, Vol. 12(4), 297-300)

We hold that words can be encoded or recognized more efficiently than nonword letter strings due to the presence of familiar letter clusters that are processed as units. The present study was designed to provide converging evidence for the assertion made by Taylor, et al. (1977) that mixing letter cases disrupts encoding processes for words and thereby reduces the word advantage in the same-different task. We used a visual search task presenting a single target letter on each trial followed by a word or nonword display. The subject was to make a positive response if the target was in the display and a negative response otherwise. The displays were either intact (i.e., printed in all upper- or all lowercase letters) or mixed (i.e., upper- and lowercase letters alternated within the strings). If the negative effect on word processing due to mixed letter cases is localized in recognition or encoding processes only, then there should be no interaction between the number of display letters and the intact vs. mixed-case variable. On the other hand, if the visual familiarity of the displays affects letter comparison time, then the slopes of the functions relating mean response times to number of letters should be steeper for mixed-case displays than for intact displays. The response times for nonwords should be unaffected by letter-case manipulations, as both encoding and comparison processes are assumed to be letter-by-letter in the absence of familiar letter clusters.

Method

The subjects were nine University of Kansas undergraduates who participated in five sessions on separate days. The stimuli consisted of one- and two-syllable words and nonwords, four, five, or six letters in length. The nonwords were unpronounceable anagrams of the words. All of the stimuli were used once each in the three letter-case conditions: intact uppercase, intact lowercase, and mixed upper- and lowercase. One third of the stimuli were used on negative trials; that is, a target letter was randomly selected from those letters not included in the display. Half of the positive target letters in each condition physically matched one of the display letters, whereas the other half matched a display letter in name only. The stimuli were presented in a tachistoscope. Each subject viewed all 540 experimental stimuli once during five test sessions. Each trial began with the target letter, followed by a masking field, then the display. The subjects were instructed to respond rapidly and accurately, and response times were recorded from the display onset until one of the response switches was pressed.

Results

The results replicated similar measurements of search times for single-letter targets in horizontal strings of letters (e.g., Atkinson, Holmgren, &

Juola, 1969; Chiang & Atkinson, 1976; Gilford & Juola, 1976; Juola, Schadler, Chabot, & McCaughey, 1978; Townsend & Roos, 1973). That is, mean response times increased linearly with the number of display letters, and responses were faster on positive trials than on negative trials. Response times were also shorter when the displays were words rather than nonwords. The small response time advantage for intact lowercase letters over intact uppercase did not interact with any other factor. Response times were about the same for intact and mixed-case nonwords, but mixing letter cases in words significantly delayed search performance.

The other striking feature of the data is the discrepancy in slopes, the effects of number of display letters on search times, for word and nonword displays. For words, the slopes were less on positive trials than on negative trials. The slopes for mixed case and intact words on positive trials did not differ significantly from the slopes on negative trials. The slopes for intact nonwords were significantly smaller on positive trials than on negative trials, and the slopes for mixed-case nonwords were marginally smaller on positive trials.

Discussion

The results supported the hypothesis that mixed letter cases can disrupt word recognition processes by destroying the familiar units normally used in word perception. Word recognition seems to depend on the familiar visual configurations of letter clusters found in common words. The lack of familiar letter clusters in the nonwords did not result in processing differences between intact and mixed-case displays, as would be expected if a letter-by-letter processing strategy were used. The results provide converging evidence for the Taylor, et al. (1977) conjucture that familiarity affects encoding processes. Since the effects of number of letters were independent of whether the displays were mixed or intact, it appears that the initial encoding process was affected by visual familiarity but that subsequent comparison processes were not (see also Gilford & Juola, 1976).

Searching for Syllable, Word, and Category Targets in Intact and Scrambled Prose

Dennis A. McDermott, Timothy J. Miller, and James F. Juola

One aspect of reading that has been of particular interest in our research is the unit of information used in the early states of visual processing. Letters, spelling patterns, syllables, words, and phrases have all been suggested as potential processing units. Two factors stand out as particularly important in pursuing this line of inquiry. First, the reading process should be evaluated in a task that requires the subject to read meaningful prose for comprehension. Letter and word preception experiments, which constitute the bulk of previous research, have helped determine what skills the reader is capable of using under different task demands. However, these tasks cannot account for the effects of context and the attention to comprehension that characterize prose reading. Second, the developmental progression in the use of different processing units should be identified. Beginning readers might employ different types of information from skilled readers, and the ability to use larger processing units (e.g., words or phrases) might be dependent upon facility in using smaller units (letters or syllables).

There has been some work relevant to each of these points. In a series of experiments, Ball, Wood, and Smith (1975) had adults search for various targets through meaningful or scrambled text. The targets were words, syllables, and semantically-defined items; in the first two experiments, using a between-subjects design, response times were fastest for locating the semantic targets in both meaningful and scrambled prose. The semantic-word search difference disappeared in a within-subject design in their third experiment. Although the Ball, et al. results might be taken as evidence that the units of processing in reading are larger, or at least more abstract, than single words, there were several shortcomings in their methodology that necessitated further research with adults before we began work with children.

This experiment was designed to make the Ball, et al. (1975) search paradigm more relevant to a normal reading situation. Adults read paragraphs and were sometimes asked comprehension questions about their contents immediately after reading them. Because semantic information is contained within the visual unit of a word, we expected the recognition of that visual unit to precede the extraction of semantic information, although the two processes could occur in parallel (see Wickens, 1972, for example). It would be of theoretical interest to replicate the semantic superiority effect reported by Ball, et al. (1975) and Cohen (1970) for words appearing in a normal paragraph context.

Method

Subjects. The subjects were 23 University of Kansas students (10 males and 13 females) who participated for class credit or for a payment of $2.50.

Materials. The stimuli to be read consisted of 60 test paragraphs and nine practice paragraphs (see sample paragraphs in Table 1). The paragraphs were original compositions, each had three sentences and varied from 26 to 30 words in length. The paragraphs were typed double-spaced onto blank white 6" x 9" (15.2 x 22.9 cm) cards for presentation in an Iconix three-field tachistoscope. The typing was done using an IBM Selectric II typewriter and Courier typeface. All paragraphs were typed in four or five lines, with an average of about six words per line. They were viewed from a distance of about 95 cm, yielding a visual angle of about 5 deg for each line of type.

A single target word was chosen for each paragraph, and these were located equally often in the first, second, and third sentences. Each word was chosen so that it could be used for each of the three target conditions. That is, all target words were two- or three-syllable, high-dominant exemplars from one of 37 categories chosen from the Battig and Montague (1969) category norms. Subjects were informed of these characteristics of the target words in the instructions. The names of the semantic categories of the target words did not appear in the paragraphs. The targets were typed onto separate cards. Word and syllable targets appeared in all upper case letters and category targets in mixed type to keep them visually distinct. The syllable targets were followed by hyphens if they were the first syllables of the target words, they were surrounded by two hyphens if they were central syllables, and they were preceded by single hyphens if they were final syllables. Semantic targets were defined by phrases (e.g., "A Bird") to avoid confusion with the word targets.

Procedure. Each trial began with a tone signal from the experimenter. Upon hearing it, the subject pressed a foot switch that illuminated the target for 1500 msec, followed by an illuminated blank field for 500 msec, after which the paragraph appeared, also centered in the field. The subject read through the paragraph and pushed a button with the dominant hand immediately on finding the target. The subject continued reading after this response was made and pressed another button with the non-dominant hand when finished. This button was used to record times for negative responses, when no target was present in the paragraphs, and reading times when no target was presented in advance. It also turned off illumination of the paragraphs.

Fifteen of the paragraphs were preceded with the phrase "Normal Reading Paragraph" in place of a specific target, and for these trials subjects were to press the button assigned to the non-dominant hand when finished reading. These trials were used as a measure of the subjects' reading speed for the paragraphs when no target was given. The other 45 paragraphs were preceded by equal numbers of syllable, word, and category targets. Of the 15 paragraphs in each of these target conditions, four had the target located in the first sentence, four in the second, and four in the third; in the remaining three paragraphs the given target was not presented, and a negative response was required. The paragraphs were arranged in a random order to be presented to the subjects. After each quarter of the subject pool had been run, the target type of each paragraph was changed. In this way work, category, syllable, and "Normal Reading" targets were used for each paragraph equally often.

After every negative paragraph and one-fourth of the positive paragraphs, an oral true-false question was asked about the contents of the paragraph. These questions included verbatim facts that could be verified or refuted with respect to the information read, or they were valid or invalid inferences drawn from the paragraph (examples of the comprehension questions are shown in Table 1).

Results

Mean reading rates were determined for the normal reading trials for each subject from the time between paragraph onset and the pressing of the response button with the non-dominant hand. The mean rate across subjects was 213 words per minute (WPM). This rate can be compared directly with the rates obtained for the various target search conditions when the targets were not included in the paragraphs. The mean rates across

Table 1

Presented is one example each of the intact (used in Experiment I) unrelated, and scrambled paragraphs (used in Experiment II) preceded by the target to be searched for in that paragraph in the word, category, and syllable target conditions, respectively. The paragraphs are typed in the format in which they appeared to the subject.

BOURBON, An Alcoholic Beverage, BOUR-

The cub reporter detected bourbon on Senator Plinth's breath. She told her editor the congressman was intoxicated durint legislative sessions. He replied that she would have to substantiate her story.

LEMON, A Fruit, LEM-

Slices of lemon surrounded the punch bowl. About a decade ago, the local draft board was burned on that holiday. Until then, she could have little company.

TERMITE, An Insect, TER-

The occurred to cups he often them Italian termite finest punch more. Substantial their and newlyweds ventilated 20 night gifts crowded. Well the house a this their with number.

subjects on negative search trials were 176 WPM for syllable targets, 227 WPM for word targets, and 215 WPM for category targets. A one-way analysis of variance of the negative trial response times was significant, F (2, 66) = 6.39, p = .005. The rate for the syllable target condition was significantly slower than that for the no target condition, t (22) = 4.05, p .001, whereas searches for words and category exemplars apparently did not affect reading rate.

The total response times on negative trials in the three target conditions along with the corresponding positive response times are presented in Figure 1. The positive data are reported separately for targets located in the first, second, and third sentences of the paragraphs. Target detection times increased linearly with the serial location of the target in the paragraph, and the straight lines in Figure 1 represent least-squares fits to the data. The slopes of these lines provide another estimate of the reading rates while searching for the various targets, and these were determined to be 203 WPM for syllable targets, 235 WPM for words, and 209 WPM for categories. Reading rates estimated for the three types of target searches on positive trials were ordered in the same way as the negative response times, although they were not significantly different from one another. That is, the interaction involving target type and serial position of the target in the paragraphs was not significant; this can be seen in the near-parallel functions in Figure 1. Reading rates for all target search conditions on positive trials also did not differ significantly from the 213 WPM rate for the normal reading condition. The overall effect of target type, collapsed across serial positions, was significant, however, F (2, 44) = 11.7, p .001, as was the main effect of target serial position, F (2, 44) = 378, p .001. A Newman-Keuls analysis showed that the mean response time for detecting word targets was significantly less (p .05) than the mean times for either category or syllable targets, and the latter did not differ significantly from each other.

The overall miss rate on trials in which the target was present in the paragraphs was 3.8 percent. The only significant effect found in these data was target serial position: 1.0 percent of the targets in the first sentences were missed, 4.5 percent of those in the second sentences were missed, and 5.9 percent of those in the final sentences were missed, F (2, 64) = 5.86, p = .005. The false alarm rate was 1.3 percent, and no analysis of these errors was made.

Erroneous responses to comprehension questions were made after 16.1 percent of the semantic category searches, 10.2 percent of the word searches, and 8.6 percent of the syllable searches. Although these error rates did not differ significantly from one another, they did differ significantly from the error rate of 4.5 percent for comprehension questions asked after the normal reading paragraphs, F (3, 88) = 5.76, p .01, multiple comparisons based on a Newman-Keuls analysis.

Discussion

The results demonstrated that in most cases normal reading was only minimally disrupted by the addition of a search task for a specific word or syllable target or for any exemplar of a given semantic category. The

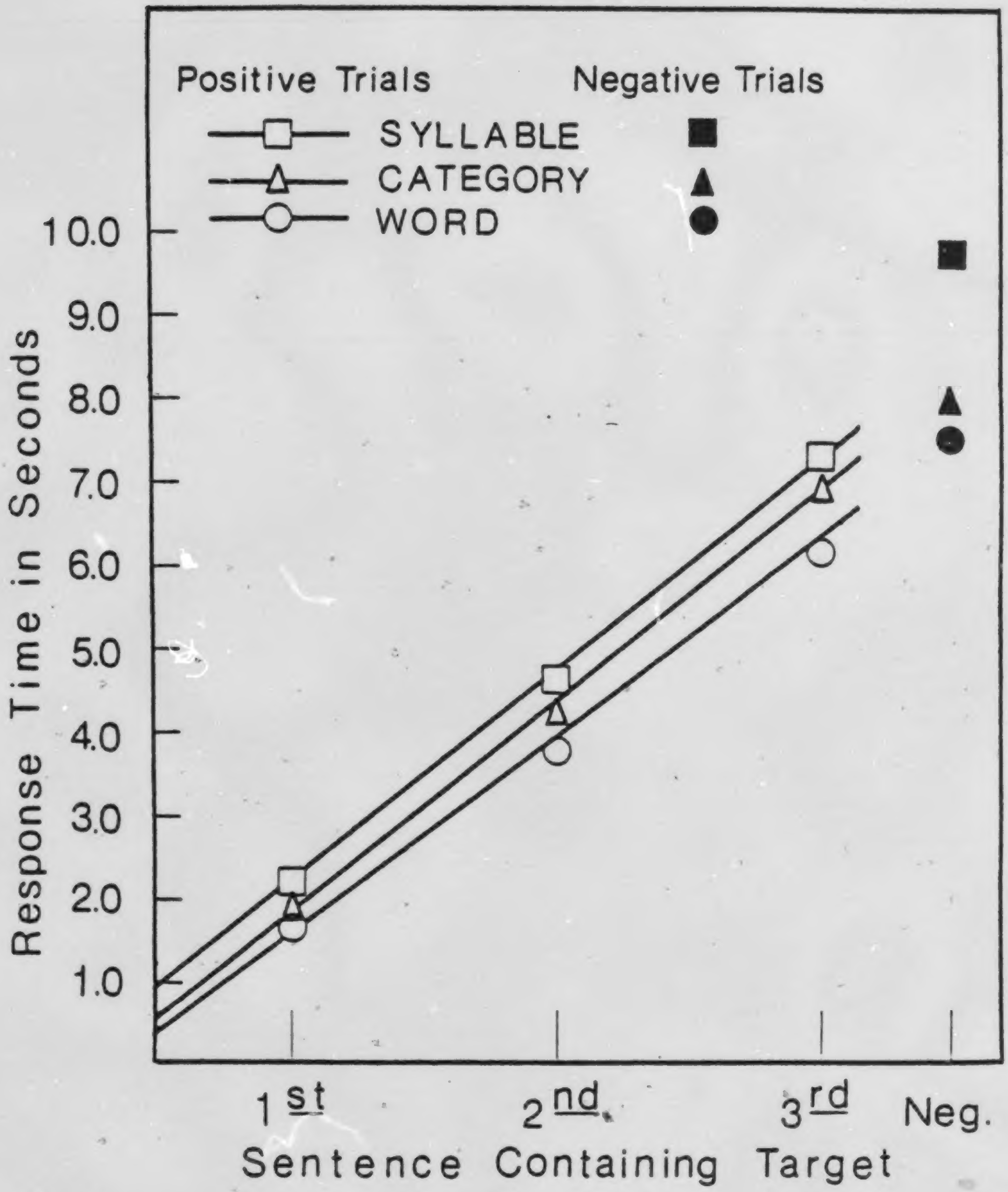


Figure 1. Best-fitting functions relating response times for syllable, category, and word targets to the positions of the targets in the paragraphs (Experiment I). Spacing along the abcissa is by the mean number of words preceding the targets. Negative trial response times are near the right margin.

slopes of the target position functions shown in Figure 1 were approximately the same for all three target types, indicating that the paragraphs were read at about the same rate while searching for the various target types. Word targets were found faster than the other types, however, and syllable targets resulted in slower times on negative trials than the times recorded for the other negative trials and for the normal reading paragraphs. Apparently the target search task made some demands upon the subjects, as comprehension measured by our test questions was only about 88 percent for the paragraphs read in the search conditions whereas it was about 96 percent when reading was done without a concomitant search.

The search results failed to find the superior detection rate for semantically-defined targets; this is contrary to results by Ball et al. (1975, Exps. I and II). Our results indicate that the paragraphs are processed word-by-word and that words are closer to the primary units of processing in reading than are syllables or superordinate categories of the words. At a stage later than word recognition in reading, semantic information or knowledge of syllabic subunits of the words can become available as a result of further processing of the recognized words. Whereas there is wide support for the notion that semantic information is automatically extracted from familiar words (e.g., Stroop, 1935; Warren, 1972), this process does take time and in general depends on the same types of information that enables word recognition. That semantic information is apparently extracted from words faster than the constituent syllables can be identified is contrary to reading models favoring a serial, phonemically-based analysis of the word prior to accessing meaning (e.g., Gough, 1972; Mackworth, 1972).

The fact that target detection times increased additively for all target types across the serial positions of the targets in the paragraphs leads to the following interpretation. The units of processing in normal reading are at least as large as single words. Syllables can be identified in words as they are being read, but this process apparently occurs after word recognition rather than as a component of the recognition process. Although it is possible than some semantic information about a word becomes available prior to its actual identification (e.g., Wickens, 1972), words in text are recognized faster than the semantic categories to which they belong. This is not to deny that higher-order semantic information about words or phonological codes based on syllable-like units are functional in reading, but such information seems to be activated only after individual words are recognized. Phonological codes of words could be generated after the words are recognized to be used in determining sentence meaning and retaining sentence components in active memory while these determinations are being made (Kleiman, 1975).

Experiment II

A second experiment was undertaken in an attempt to replicate some of the results of Experiment I and to examine the effect of context on the reading process. Ball et al. (1975 Exp. I) reported an advantage for detecting semantic targets over syllable targets which persisted when sentences were scrambled into ungrammatical, meaningless word strings. Although their Experiments I and III used whole words as targets, they did not involve word searches through ungrammatical strings. Semantic targets might be detected faster than syllables if words are recognized as wholes and semantic information stored in memory about them is activated sooner than information about the words' constituent syllables. Providing the word with a meaningful context presumably enhances the accessability of relevant semantic information, thus we would expect the advantage for semantic searches over syllable searches to be greater for intact than for scrambled paragraphs. Altering grammaticality of prose reduces information redundancy from syntax as well as semantic context, a reduction that could affect the detection rate of physical features of prose represented by word and syllable targets.

Method

Subjects. The subjects were 20 University of Kansas students who participated either for a cash payment of $2.50/hour or for credit in an introductory psychology class. Four of the subjects were graduate students, and 16 were undergraduates; nine were males and 11 were females.

Materials. Thirty-six paragraphs were randomly selected from a pool of 72 paragraphs which included the 60 experimental paragraphs from Experiment I plus 12 new paragraphs similar to them. These were used to make 36 new paragraphs comprised of three unrelated sentences and 36 additional paragraphs composed of strings of unrelated words. Examples of these paragraphs appear in Table 1. The three types of paragraphs will be referred to as normal, unrelated, and scrambled paragraphs, respectively. For each of these three paragraph types, a single target word was chosen, and across all paragraphs they were located equally often in the first, second, and third sentences. As in Experiment I the target words were used for syllable, word, and superordinate category label targets, and the same types of targets were used on negative trials. All paragraph and target types were arranged into two different random sequences for presentation to different halves of the subject group.

Procedure. Every subject participated in three experimental sessions, one on each of three consecutive days. Each session began with nine practice trials, and a practice set using materials similar to the experimental stimuli was used on each day. During each session, one observation was recorded in each cell of the design involving paragraph type (normal, unrelated, or scrambled), target type (syllable, word, category), and target serial position (first sentence, second sentence, or third). In addition, one paragraph in each of the target type by paragraph type cells did not include the target. Thus each session included 27 positive trials and nine negative trials.

The procedure for each trial was the same as in Experiment I. Each target was presented in the center of the field of view for 1500 msec followed by a 500 msec blank field and then the paragraph. The subject read through the paragraph, and pressed one button with the dominant hand if a target was found and another button with the nondominant hand when finished reading the paragraph. The latter button also turned off the paragraph illumination. Except for the scrambled paragraphs, subjects were asked comprehension questions after all negative trials and after one-quarter of the positive trials. For intact paragraphs the question referred to material in any one sentence or combination of sentences.

Questions on the unrelated paragraphs concerned information in only one of the sentences.

Results and Discussion

Mean reading times were determined for each subject from the time to push the negative response button on trials on which the target was not present in the paragraph. These times were then averaged and mean reading rates were determined for the three target conditions. These were 175 WPM for syllable targets, 224 WPM for words, and 197 WPM for categories, F (2, 38) = 35.8, p .001. All three means differed significantly from one another as determined by a Newman-Keuls analysis (p .05). These reading times are in the same order as those found for the three target types in Experiment I, but they are all somewhat slower. This overall difference may be attributed to the fact that reading rates, as determined from negative trials, were slower in the scrambled paragraph condition (182 WPM) than for the unrelated (203 WPM) and intact (198 WPM) paragraphs, F (2, 38) = 10.5, p .001.

A 3 x 3 x 3 repeated-measures analysis of variance was performed on the response time data for positive trials. The factors were paragraph type (intact, unrelated, and scrambled), target type (syllable, word, or category), and position of the target in the paragraph (first, second, or third sentence). Significant main effects were found for target serial position, F (2, 38) = 241, p .001; target type, F (2, 38) = 18.2, p .001; and paragraph type, F (2, 38) = 10.7, p .001. None of the interactions were significant. As is evident in Table 2 and Figure 2, the serial position effect is due to a linear increase in response time as the target's location changes from the first to the second then the third sentence. The main effect of target type shown in Table 2 is due to the same ordering of target detection times found in Experiment I; i.e., words were most rapidly found followed by category targets and then syllables. A Newman-Keuls analysis found that the response times for syllable targets were significantly longer than those for words and categories, and that the latter did not significantly differ from each other. The paragraph type effect shown in Figure 2 is due to the more rapid processing of intact and unrelated paragraphs than scrambled paragraphs.

The targets were missed in the paragraphs on 3.2 percent of the positive trials, and the presence of targets not in the paragraphs was falsely reported 3.8 percent of the time. An analysis of the miss data revealed that, as in Experiment I, errors increased as the serial positions of the targets in the paragraphs increased, from 1.9 percent for targets in the first sentence, to 3.0 percent for those in the second sentence, to 4.8 percent for those in the third, F (2, 38) = 5.1, p = .011. Word targets were missed less often (1.1 percent) than syllable targets (3.3 percent) and category targets (5.2 percent), F (2, 38) = 6.1, p = .005. Targets in the unrelated paragraphs were missed less often (1.1 percent) than those in intact and scrambled paragraphs (4.2 and 4.4 percent, respectively) F (2, 38) = 6.4, p = .004. For the false alarm data, two effects reached significance. Only 1.1 percent of the false alarms occurred for word targets, whereas the rates were 3.9 percent and 6.6 percent for syllable and category targets, respectively, F (2, 38) = 3.5, p = .04. The interaction between target type and paragraph type was also significant, F

Table 2

Mean Response Times for Target Search Trials in Experiment II

(Error percentages are shown in parentheses)

		Target Type			Paragraph Type Means	
Paragraph	Sentence Con-	Word	Category	Syllable	Positive Trials	Negative Trials
	1	1.67 (1.7)	1.95 (3.3)	2.52 (0.0)		
Intact	2	3.76 (0.0)	4.37 (5.0)	4.48 (5.0)	4.37 (4.2)	
	3	6.24 (0.0)	6.88 (1.2)	7.46 (12.0)		
	Target Not Present	7.67 (0.6)	8.18 (6.1)	9.90 (5.6)		8.58 (5.0)
	1	1.79 (0.0)	2.04 (1.7)	1.75 (0.0)		
Unrelated	2	4.20 (0.0)	4.17 (1.7)	5.20 (0.0)	4.41 (1.1)	
	3	6.69 (1.7)	6.50 (1.7)	7.40 (3.3)		
	Target Not Present	7.86 (0.6)	8.06 (1.7)	9.20 (1.1)		8.37 (3.3)
	1	1.95 (1.7)	2.59 (5.0)	2.73 (3.3)		
Scrambled	2	4.56 (0.0)	5.39 (10.0)	5.24 (5.0)	4.94 (4.4)	
	3	7.22 (5.0)	6.78 (8.3)	7.97 (1.7)		
	Target Not Present	8.20 (2.2)	9.51 (7.8)	10.23 (3.3)		9.31 (3.3)
Target Type Means	Positive Trials	4.23 (1.1)	4.52 (5.2)	4.97 (3.3)	4.57 (3.2)	
	Negative Trials	7.91 (1.1)	8.58 (6.6)	9.74 (3.9)		8.75 (3.8)

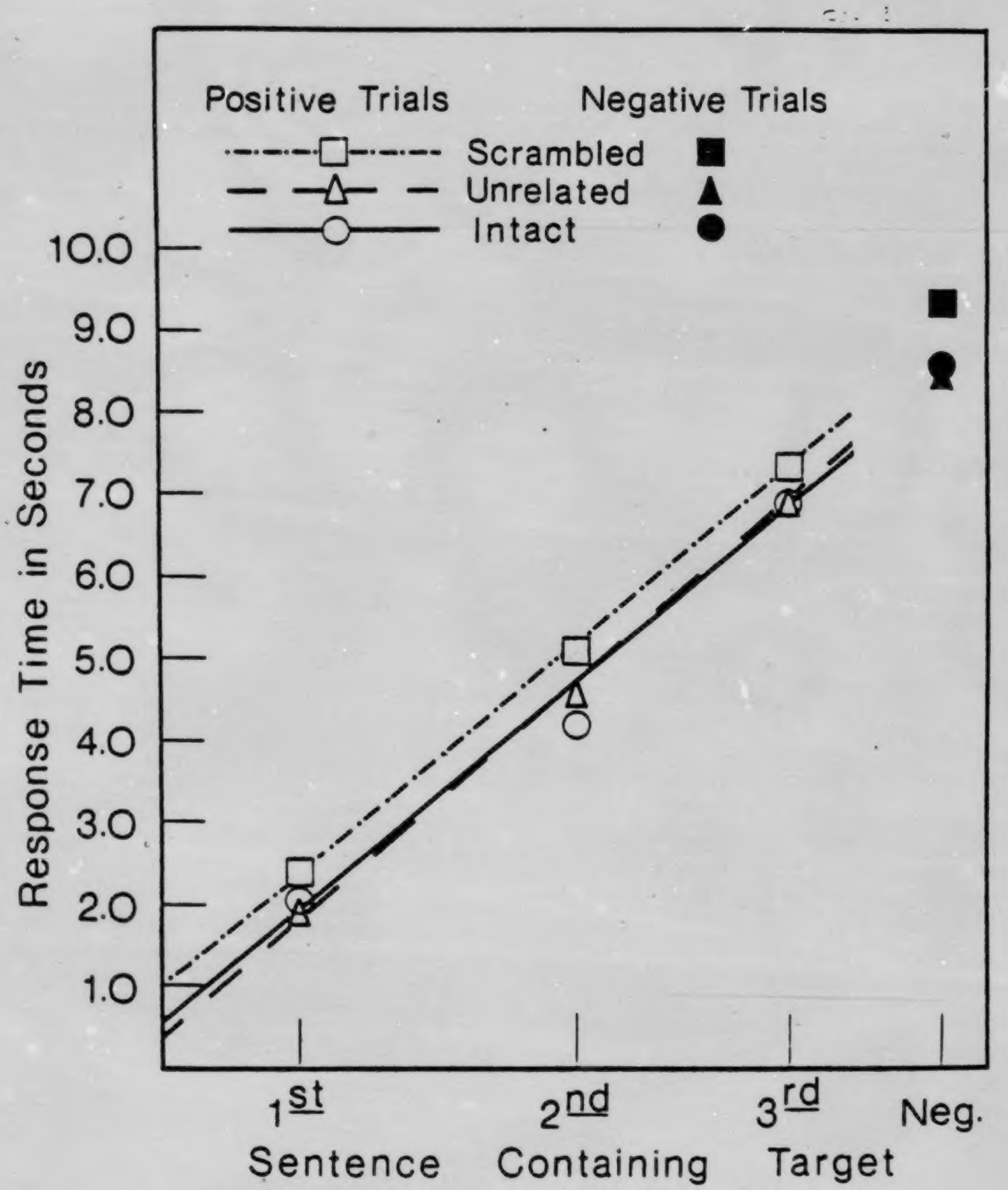


Figure 2. Best-fitting functions relating response times for scrambled, unrelated, and intact paragraphs to the positions of the targets in the paragraphs (Experiment II). Spacing along the abcissa is by the mean number of words preceding the targets. Response times for negative trials are near the right margin.

(4, 76) = 5.3, p .001. This was due to the fact that the order of the false alarm rates was changed for the scrambled paragraphs, for which errors were more likely for syllable targets and less likely for category targets. All of the error data and response time data for Experiment II are presented in Table 2.

In general, the data for the intact and unrelated paragraphs in Experiment II closely replicated the results of Experiment I. However, replacing the normal sentence context with strings of scrambled words reduced reading speed. These results contrast with those of Lefton and Fisher (1976) who reported that search times for word targets were significantly shorter through scrambled words than through normal paragraphs. In their research, the subjects were instructed simply to scan the paragraphs for the presence or absence of the targets, and no comprehension questions were asked. Apparently scanning rapidly for targets can be hindered by the presence of meaningful relations among the words in normal text, but instructions to read the passages normally produces a processing set that is disrupted by scrambled prose.

Fisher (1975) has maintained that intact prose can be read more rapidly than meaningless prose because information from words in the periphery of the visual field can be used to facilitate the processing of the word being fixated (this hypothesis is taken from the analysis-by-synthesis theory of Hochberg, 1970). However, research by Rayner (1975) and McConkie and Rayner (1975, reviewed by Theios and Muise, 1975) indicates that each fixation allows for the accurate resolution of only about 10 characters and spaces to the right of the fixation point in normal text, and that little semantic information can be abstracted from words more peripherally located than that. The facilitative effect of meaningfulness in reading prose is then apparently due to the more rapid processing of recently fixated text through the use of information processed earlier. That is, previous semantic analyses of the text being read can place certain constraints on the form of the current text input, such that perceptual and conceptual analyses of the words fixated can proceed more rapidly.

The reading times and target detection times were nearly identical for normal and unrelated paragraphs, whereas there was a large difference between these response times and those for the scrambled paragraphs. An explanation for this difference is suggested by Garner (1962) who pointed out that information redundancy is greatest within words and somewhat less between words. Just so, the facilitating effect of information redundancy from semantic context, grammar and word-order on reading should be far greater between words than between sentences. The scrambled paragraph condition subtracts the facilitative effects of between-word information redundancy from the normal condition; the unrelated sentences condition subtracts the much smaller facilitative effect of redundancy between sentences.

General Discussion

The results of Experiment I indicate that the reading rate for short paragraphs is only minimally affected by the requirement of a concomitant search task. Processing rates were generally unaffected by the requirement to search for a word or semantically-defined target, although syllable searches reduced reading rates. The search task, it seems, did impose some demands on the processing capacities of the subjects, as there were lower reading comprehension scores for paragraphs read while searching for a target vs. those read without a concomitant search. Target detection times increased in a parallel linear fashion for all three target types as the sentence location of the targets changed from the beginning to the end of the paragraphs. Overall, however, word targets were detected with the shortest response times, followed by the semantic targets and then syllables. The failure to find an advantage for the semantic targets over words did not replicate some of the results reported by Ball, Wood, and Smith (1975, Exp. II), and we believe that part of this difference is because the present experiments were conducted to more closely produce a situation like normal reading for comprehension.

Experiment II included paragraphs constructed of unrelated sentences and scrambled word strings as well as normal, intact paragraphs. The response times for reading and searching through intact paragraphs replicated those for Experiment I; paragraphs composed of unrelated sentences were searched at about the same rate as normal paragraphs, and scrambled paragraphs required significantly more time for processing.

A general model of the reading process that could account for the present results is one in which the information most readily available to the reader is the identities of individual words. Semantic and syllabic information can be obtained only with additional processing. It seems reasonable to assume that higher-order semantic information is available at a processing stage following the identification of words in text. Graphemic units smaller than words are apparently not functional as units of processing in normal reading for comprehension, although this conclusion needs to be qualified somewhat if based only on the present data comparing search for words and syllables. We feel we can safely generalize our results to other syllable-like units such as the vocalic center groups proposed by Smith and Spoehr (1974) as the perceptual units of analysis in reading, and although the syllable unit is not generalizable to all subunits of words, the data run contrary to models such as those of Gough (1972) and Mackworth (1972) in which the word code is accessed after the serial accumulation of its phonological subunits. We have also argued on other grounds that the perceptual units in skilled reading are at least as large as common words (Juola, Leavitt, and Choe, 1974; Friedrich, Schadler, and Juola, 1979).

Current reading models into which the present data can be integrated include those of Kleiman (1975), LaBerge and Samuels (1974), and Massaro (1975). LaBerge and Samuels' model, for example, is divided into components of attention and visual recognition processes for language materials. The recognition processes are considered to proceed along a series of stages after a given visual input, including feature detection, letter coding, spelling pattern coding, word coding, phonological coding, and memory coding. Some of the stages between feature coding and memory coding can be omitted by the skilled reader, and others will demand more or less attention depending on the difficulty of the material. Phonological coding between word recognition and comprehension is an idea dating at least to the time of Huey (1908) and is considered necessary in most current reading models. One reason for relying on phonological coding in reading could be that auditory working memory has a larger capacity for linguistic units than its visual counterpart. Visual working memory is usually assumed to be occupied in processing the current stimulus while auditory memory retains previously processed information until it can be integrated into larger meaningful units (Kleiman, 1975; Massaro, 1975). There is also some current research (Scarborough, Gerard, and Cortese, 1979) that indicates phonological coding is unnecessary for lexical access.

The present data could be interpreted in terms of these models by assuming that the word recognition stage is not one that practiced readers normally omit while reading simple paragraphs. Moreover, if the syllable is considered to represent either a perceptual unit smaller than a word or a unit of processing in a phonological coding stage, then most skilled readers apparently do not rely on these units prior to word recognition. Of course it could also be argued, as Ball et al. (1975) point out, that units smaller than words are functional in perception, but are generally unavailable to conscious processes until after words and other "identification units" which include them have been processed. Although the semantic superordinate is only one type of relation that could be retrieved about words in comprehending text, it appears that semantic analysis of a word follows its identification. Further research is needed to determine what, if any, semantic information about words is directly available prior to their recognition while reading for comprehension.

Developmental Changes in Units of Processing in Reading

Frances J. Friedrich, Margaret Schadler, James F. Juola
(Full report in Journal of Experimental Child Psychology,
1979, 28, 344-358.)

The developmental literature suggests that children can use a variety of visual units, depending upon task demands, early in the acquisition of reading skills (see Doehring, 1976; Wanat, 1977). An indication of a developmental progression in the use of orthographic and lexical information can be found in the first two studies we reported here employing the visual search task. Children searching for a single letter in displays of words, orthographically regular pseudowords, and irregular unpronounceable nonwords show knowledge of orthographic structure as early as second grade. The word advantage demonstrated by the pre-second grade children suggested to McCaughey, Juola, Schadler and Ward that the benefits of processing meaningful words emerge prior to benefits gained by knowledge of orthographic regularity. It is also interesting that, although response speed and accuracy improved with age, second and fourth grade children and adults appeared to search letter strings in much the same way.

The present study was designed to identify functional units that children use in reading meaningful text and to evaluate the relative difficulty of employing different types of units. A visual search task was used; subjects were asked to locate a prespecified letter, syllable, word, or semantically-defined target as they read through sentences. The response times for locating the different targets should reflect the relative accessibility of these units during prose reading. Reading times and comprehension scores were obtained for reading comparisons across search conditions and with performance in a normal reading task.

Method

The subjects were 20 second and 19 fourth graders and 20 college students. The stimuli were rear-projected to each individual. The target items included letters, syllables, words, and superordinate category labels. In addition to these four search conditions there was also a normal reading condition in which the sentence was to be read for comprehension but not searched. The sentences were considered to have three segments (serial positions) of three words each. Comprehension questions were asked after half of the sentences.

All subjects received 30 practice trials and 120 test trials. Each consisting of the presentation of a target followed immediately by the sentence. The subjects were instructed to read the sentences for comprehension at their normal speed. In addition, they were told to press a key immediately with the dominant hand if they saw the target and to press a second key with the nondominant hand when they finished reading the sentence.

Results

Performance was evaluated on the basis of four different measures: (1) search time, the time needed to locate the target in the sentence, (2) reading time, the time needed to read the entire sentence, (3) search errors, and (4) comprehension scores. Search times decreased with age and across target conditions from letter (slowest), syllable, category, to word (fastest). Search time differences among target type conditions were greatest for the second graders and smallest for the adults, and suggested that performance in the category condition showed greater improvement between the second and fourth grades than did the other targets. Syllable search rate decreased with age faster than letter search. Search rates increased with grade level; within each grade search times increased linearly across serial position, indicating that the sentences were searched at a steady rate. Words showed the smallest response time increase across serial position, followed by category, syllable, and finally letter targets. Reading times decreased across letter, syllable, category, and word conditions; target type had more effect on the reading times for the second graders than for the adults. When reading times were converted to rates, the relative changes in rate that occurred in a given search condition were approximately equal for all grade levels.

Search errors decreased with grade level and across the letter, syllable, category, and word target conditions and also across serial position. The second grade again showed the greatest differences among target type conditions. Whereas the fourth graders and adults made most of their search errors in the letter condition, the second grade children made more errors when searching for syllables than for letters.

Adults made fewer errors on comprehension questions than the children. The greatest proportion of errors occurred in the syllable condition, followed by the category, normal, letter, and word conditions, in that order.

Discussion

The search time, reading time, search error, and comprehension measures provided converging evidence that the whole word is a preferred processing unit in reading single sentences. Word targets were located most quickly and accurately by all age groups. Perhaps even more compelling, performance in the word search and normal reading conditions did not differ from one another in either reading rate or comprehension. Thus it appears that word search and normal reading involve much the same basic processes.

Subjects at all three grade levels reduced their reading rate by the same proportionate amounts for the various search tasks, indicating that the children and adults employed similar strategies for maintaining comprehension while executing the search tasks. However, the skill with which this additional processing took place, as indicated by search times, was related to grade level. Both the search error and the comprehension error data suggest that the younger children have difficulty processing syllable units. It could be that the children simply did not use syllables as single units, thus possibly increasing memory load enough to reduce comprehension.

There may also be a more general relationship between visual processing and comprehension. Rapid processing of visual information appears to aid comprehension by reducing demands on memory and allowing more time for inferential processes (Kleiman, 1975; Perfetti & Lesgold, 1979). If syllable processing skills develop more slowly than whole word skills, as Doehring (1976) has also suggested, those children who can use syllable units efficiently are probably also processing words more rapidly.

In summary, all subjects identified word units more rapidly and accurately while reading than syllable or letter units, or category membership. Performance in the word search condition was in fact comparable to normal reading in terms of reading rate and comprehension. The children showed rapid improvement in the category search between the second and fourth grade.

II. ACCESSING THE MEANING OF WORDS

Our second line of research is concerned with the processes by which meaning is assigned to words. Two initial studies were completed under the auspices of this grant and are reviewed here. The first study used a method similar to our visual search techniques to investigate children's memory search processes. The development of automatic processes investigated in the second study has since become a major research direction. While this latter experiment is reported in some detail here, it is being prepared for publication as the first of three experiments, the other two supported largely by NIE grant G-78-0179.

Memory Search Processes for Words and Pictures in Elementary School Children

Dennis A. McDermott, Michael E. Young, Robb M. Gilford
and James F. Juola
(Full report in Bulletin of the Psychonomic Society,
1977, Vol. 10(2), 83-84.)

The present study was designed to investigate stimulus encoding and memory comparison processes in children. The problem was to determine whether both encoding and comparison stages of the memory search process would be affected by the probe stimulus form. We were also interested in determining if children can make comparisons between stimuli based on conceptual, rather than perceptual, information.

Method

The subjects were 25 fourth grade and 19 sixth grade students. The stimuli were slides of single typed names or outline drawings of common objects. All trials began with the serial presentation of a memory set of 2, 3, or 4 words or pictures followed by a blank red slide then the probe, which was either a member or nonmember of the memory set in word or picture form. The response was positive if the probe were the same as one of the memory set items, regardless of form, and negative if not.

Results

In general, responses were faster for picture memory sets than for words, and response times increased with set size. Performance did not differ as a function of age.

Discussion

In general, the present results using fourth and sixth grade children replicated those obtained in a similar memory search experiment with adults (Young & Juola, 1977). That is, although responses were faster and more accurate when the memory set and probe were of the same stimulus form than when the forms differed, this effect was constant with respect to memory set size. An interpretation of this result in terms of the additive-factors logic of Sternberg (1969) would be that stimulus form and memory set size affect different processing stages in children's memory search. Thus probe stimuli that match the memory items in form are encoded more rapidly. Once the encoding process is complete, however, the comparison of probes and memory items is unaffected by the form of the stimuli and probably is based on relatively abstract, conceptual representations.

Reading Ability and the Development of Automatic Word Processes

Margaret Schadler and David Thissen

Since attention is a limited capacity mechanism, automation of the perceptual processes involved in word recognition enables the reader to focus attention on meaning in the text (LaBerge and Samuels, 1974). The Stroop task is means for investigating the development of automatic word recognition. In this task, the name of a color, printed in ink of a different color, interferes with saying the color of the ink. The subject's attention is presumably focused on naming the color of the ink. A delay of the color naming response is considered evidence that the printed word has been automatically encoded and processed sufficiently to interfere with the execution of the naming task.(e.g., Posner & Snyder, 1975).

Recent investigators of the development of automatic word processing have used a variation of the Stroop task in which the subject is asked to identify pictures of objects. The interferent is a word, usually the name of another exemplar of the same category, superimposed on the outline drawing of the object. Results of studies using this picture-word variation appear to be generally consistent with those using the traditional Stroop task.

Despite a number of studies using the Stroop and picture-word tasks, the sequence of development of automatic processes involved in word recognition is far from clear. The initial appearance of interference presumably indicates automatic encoding and occurs after relatively little formal reading instruction. Such delays in responding to inconcruent pairs have been reported for second but not first graders on the Stroop task (Schiller, 1966) and late but not early first graders (Guttentag & Haith, 1978) and skilled but not less skilled second grade readers (Ehri, 1976) on the picture-word task. Interference in the Stroop task has also been shown by seven-year olds (Comalli, Wapner, & Werner, 1962; Rand, Wapner, Werner, and McFarland, 1959) and in the picture-word task for first graders (Posnansky and Rayner, 1977).

Decrements in amount of interference as a function of reading skill are important in that they should indicate greater efficiency in automatic processing. Systematic cross-sectional studies using the Stroop task reported the greatest amount of interference for the primary grade readers and subsequent decreases for older children and adults (Comalli, et al,; Rand, et al.; Schiller, 1966). Ehri (1976) reported an overall age-related decrease in interference from skilled second grade readers to fifth graders and adults. A large decrease in amount of interference between third graders and adults is also evident, although not statistically tested, in Guttentag and Haith's (1978) data. Obviously there is a general developmental pattern in which interference emerges in the early grades then typically declines in the intermediate grades and into adulthood.

There are other stimuli that interfere with the naming response, most of which have been identified in the picture-word task. Visual noise (e.g., typewriter symbols) produce significant interference for children but not adults (Guttentag & Haith, 1978). This effect could be due to distraction because such stimuli are not part of the object pictured rather than because the actual symbols are well enough known to be automatically processed. Guttentag and Haith also reported that nonword letter strings superimposed on pictures resulted in interference for late first grade and older children. Schiller (1966) also found some interference in the Stroop task for consonant strings for second grade through college level students. Both pronounceable and unpronounceable nonwords have been shown to interfere with color naming by adults (Bakan & Alperson, 1967; Klein, 1964).

These are conclusions drawn by generalizing across studies conducted over nearly 20 years using a range of subject populations and employing a variety of test procedures as well as two different tasks. Given such variety, the consistency of the general findings is remarkable. At the same time, detail and, more importantly, changes that seem to occur rapidly in the relationships among variables as a function of development may be obscured. Further, every study that we reviewed used either age or grade as the developmental indicator. Since our interest is in automatic processing as a component of skilled reading, the developmental measure should be reading skill rather than the less precise correlates of age and grade.

The present study was designed to investigate the development of automatic processes in word recognition as a function of reading skill level. The participants were classified according to reading skill at the time the Stroop task was given. We included a group of nonreaders to provide a baseline level of performance from which we could infer changes in interference as a function of reading skill development. We used the traditional color naming task to maximize the likelihood that any delay evidenced could be attributed to the nature of the interfering stimulus. As implied in Guttentag and Haith's (1978) inclusion of a visual noise condition, some interference may result in the picture-word task because the symbols are perceived as foreign to the pictured object. In contrast, colors may assume any shape, thus any interference in the color naming task can be attributed to the specific character of the interfering shape. The Stroop task should also be maximally sensitive to the emergence of interference by words and letters, since color and shape so closely correspond. We also included both incongruent (Stroop) color-word pairs and congruent (identical) color-word pairs in order to trace the development of both interference and facilitation effects.

With few exceptions (e.g., Guttentag & Haith, 1978, 1979; Posnansky & Rayner, 1977) developmental researchers have used multiple stimulus cards in which 20 color/picture-word pairs are presented at one time. Results using this procedure should be viewed with caution since interference may arise from other words and colors/pictures on the card as well as the particular interferent for that response. The single stimulus pair technique was used in this study.

Method

Subjects. The subjects were 140 Lawrence, Kansas, elementary school children whose names were randomly selected from the state population lists. Ten males and ten females from each of the following grade levels participated at the beginning of the school year: Kindergarten (mean age 5-6), 1st grade (mean age 6-8), 2nd grade (mean age 7-8), and 3rd grade (mean age 8-9). Midway through the school year, 6 more male and 9 female kindergartners (mean age 6-0) plus 14 male and 11 female first graders (mean age 6-11) were tested. A final group of 10 males and 10 females were tested during the summer prior to their entering the sixth grade. All subjects had normal or corrected-to-normal sight and normal color vision. One male who showed some evidence of color blindness was excluded from the study. Each child was paid $2.00 to come to the campus for testing.

Equipment and materials. The apparatus for the color-naming interference test was a 35mm Kodak carousel projector with a Hunter 120 Klockkounter attached. The timer was started by a photo-transistor when a stimulus slide was projected and stopped by a voice-operated-key when the child named the projected color. The stimulus slides were projected onto a 27.5 cm^2 rear-view projection screen placed on a table 90 cm in front of the subject. A Sony 2-track audio cassette recorder, used to record all trials, provided an auxiliary timing system. One track was used to record the child's response and the second to record a "beep" as each stimulus slide was advanced. If the child prematurely stopped the timer with a nonlinguistic utterance (e.g., "ah") the trial was hand-timed from the tape with a stop watch; times for these trials were subsequently corrected for the experimenter's response time.

The stimulus slides were prepared using Kodalith high-contrast 35mm film to photograph 20 - 25 cm white cards with the stimulus letters printed in black capital letters. The resulting negatives were inserted between two sheets of colored theatrical gelatin. Thus, the finished slides had capital letters in red, blue, or green print on a black background. When the slides were projected onto the screen, each letter was approximately 1 x 2 cm.

Stimuli materials were: (1) color names printed in the congruent color, e.g., the word red in red print, (2) the same words in incongruent colors, (3) unpronounceable nonwords UBD, LGNE, and NDRBE, generated from the letters in the color names and (4) strings of 3, 4, or 5 X's. The colors were red, green, and blue. Opaque slides were alternated with the test stimuli in order to stop the light flow between trials.

The test items were grouped into six blocks of 12 items each. Each block consisted of three slides from each of the four stimulus types randomly ordered, with the restrictions that no color appear more than three times in succession and no two slides for the same stimulus type appear in succession. All forms of the congruent and the incongruent stimulus slides were presented within two consecutive blocks. Eight additional slides, two examples of each of the four stimulus conditions were used as training stimuli.

The first part of the reading test consisted of a list of words, DOG, CAT, BOY, SHOE, HAT, GIRL, HORSE, RED, BLUE, GREEN, YELLOW, BLACK, BROWN, COLOR, typed in Pica capital letters on a 21.5 x 27 cm white paper. The second part was the Gilmore Oral Reading Test (Gilmore & Gilmore, 1968). The test consists of ten oral reading paragraphs, one per grade level for grades one through ten. Each paragraph is followed by five comprehension questions. The comprehension score is derived from the number of correctly answered questions adjusted for the difficulty level of the last paragraph read (Gilmore & Gilmore, 1968).

Plates 24, 25, 28, and 29 of Ishihara's (1939) color-blindness test were used to test color vision.

Procedure. A female experimenter tested each child individually in a psychology laboratory room on the university campus. The child sat at a table facing the rear-view projection screen.

The test for color-vision was given first. Subjects were asked to identify the number in the circle for plate 24. If the child did not know the number, s/he traced it with his/her finger. If the child did not identify a number correctly, s/he was also given plates 28 and 29 as a second check. When evidence of color-blindness was found, the Stroop test was not given to the subject.

For the Stroop task, each child was told to name the color of the letters on the screen as rapidly as possible without errors. On each trial a "ready" signal was given followed by the slide which remained on until the child responded. Verbal feedback and encouragement were given for correct responses. For incorrect responses, the child was asked to look again, and the experimenter waited for the correct response before terminating that display.

After each trial the experimenter recorded the response time, measured from slide outset to the verbal response, recorded any incorrect response, then initiated the next trial.

The reading test was given after the color-naming interference task. Errors and reading time were recorded for the list of 14 words, then the subjects were given the Gilmore Oral Reading Test following the standard directions (Gilmore & Gilmore, 1968).

Design

The design was 6 (comprehension level) x 4 (stimulus condition) x 3 (response color) x 2 (sex of subject) mixed factorial. The six comprehension levels were: (1) nonreaders who showed no ability to read any of the 14 list words nor the Gilmore Oral Reading Test, (2) beginning readers who were able to read one or more of the 14 words on the list but obtained a comprehension score of less than 10 on the Gilmore Oral Reading Test, (3) grade equivalent (GE-1) readers who obtained comprehension scores of 10-14 on the Gilmore Oral Reading Test, a grade equivalency range of 1.3 - 1.9, (4) GE-2 readers who obtained comprehension scores of 15-20, a range of 2.1 - 3.4, (5) GE-2 readers who obtained comprehension scores of 21-27, range 3.8 - 5.8 and (6) the pre-sixth grade children, all of whom attained reading comprehension scores above 27 (grade equivalency 6.2 or higher) comprised the sixth group in the statistical analysis. A group of ± 20 first, second, and third graders who obtained reading comprehension scores of 27 or higher were not included in this analysis. This post hoc division of comprehension scores provided for an approximately equal number of subjects in each comprehension level.

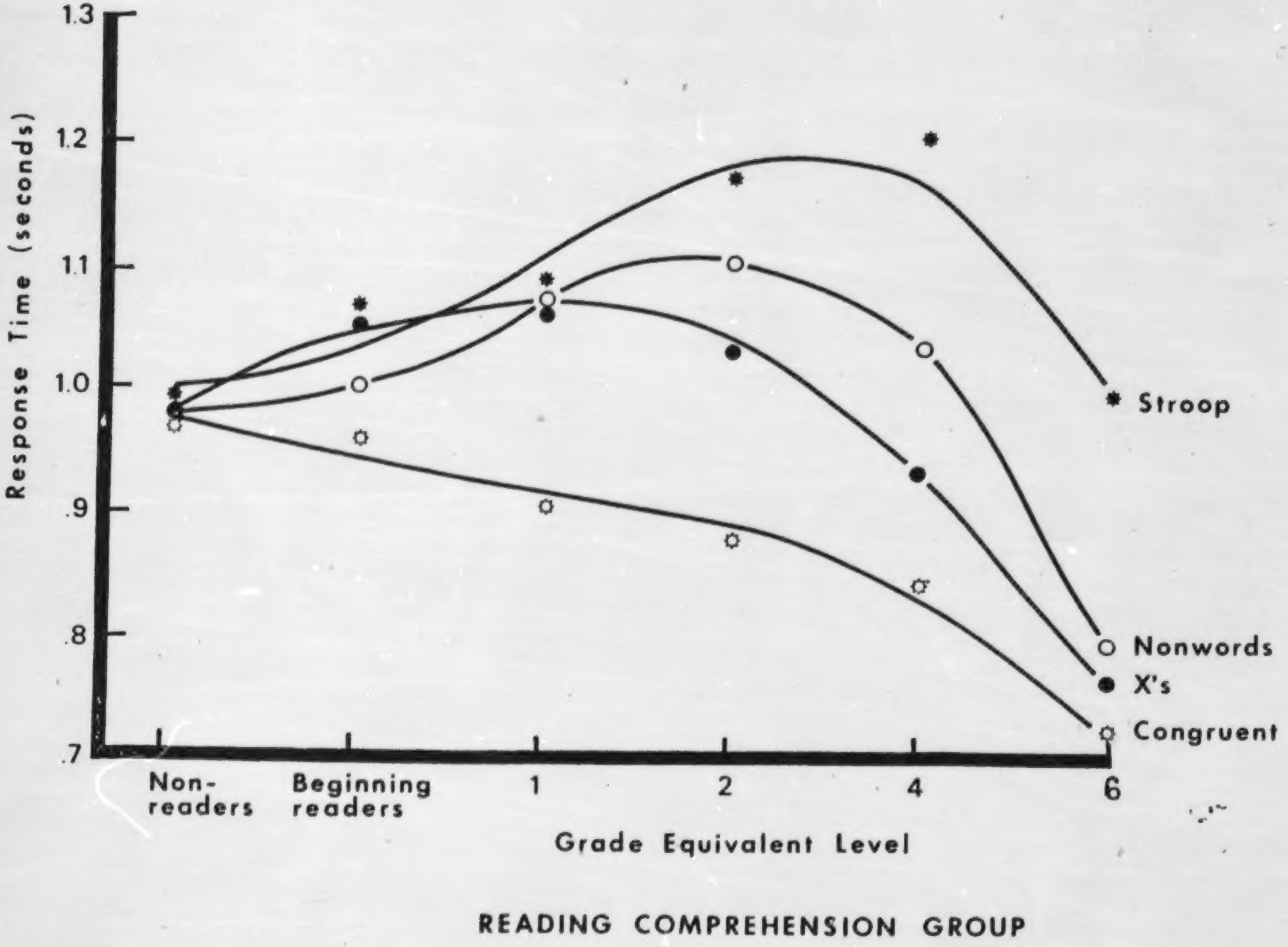
The stimulus condition x response color (4 x 3) within subject factorial completed the mixed design. Stimulus conditions were (1) inconcruent color-word pairs, (2) congruent color-word pairs, (3) colored X's and (4) colored non-words; the response colors were red, blue, and green. Each subject made six responses to each of the twelve stimulus by color conditions; the median of these six response times was the dependent variable.

Results and Discussion

The data were analyzed using the multivariate approach to the analysis of repeated measures data (described by Bock, 1975). Preliminary analysis showed no main effects of sex, nor were there significant interactions of sex with any other variable or variables. Therefore, sex was dropped from the analysis.

Response times to the stimulus conditions and reading comprehension levels were analyzed using orthogonal polynomial trend analysis. For this analysis, the reading comprehension groups were taken to be equally spaced as no specific interpretation of the polynomial effects was expected in any event. For the planned orthogonal comparisons, the incongruent color-word condition was set against the other three conditions, the congruent color-word condition against the control X's and nonsense conditions, and the X condition was contrasted with the non-word condition.

The trend analysis of response times across the six reading comprehension groups indicated that the four types of stimuli (incongruent pairs, congruent pairs, nonwords, and X's) follow different curves as reading comprehension develops. There were no significant higher-order (quartic and quintic) trends; therefore, the fitted cubic functions may be used to represent the data as shown in Figure 1.



The development of interference on the Stroop task as a function of reading skill

The response time functions for both the nonwords and the X's are essentially convex. They differ primarily in that the response time curve for the X's accelerates more quickly to an earlier peak than does the curve for the nonwords; the nonword curve peaks later then decelerates more rapidly. The differences are reflected in the significant differences between the cubic components of the trends for response times in the X's and nonword conditions ($F = 7.45$, $p = .007$). These results are evidence that both the X's and the nonwords delay the color naming response for children learning to read. Interference from nonword strings has been found previosuly (e.g., Guttentag & Haith, 1978) and was expected. Strings of X's however, are frequently used as the control condition and assumed not to interfere with color naming. This result is now being further explored.

In contrast to the convex trends across increasing reading comprehension for the X's and the nonwords, mean response times for the congruent color-word pairs exhibit an essentially linear decrease across the entire range. The difference between the quadratic components, reflecting curvature, for the congruent word pairs and for the X's and nonwords is significant ($F = 27.26$, $p < .0001$).

There are two potential factors contributing to the reading skill-related decrease in the congruent condition. One is the typical age-related improvement in response times, which is usually held to be a nonspecific effect of maturation and experience. The second is a facilitative effect of the congruent word on naming the color. Since the curve for the X's condition indicates development of interference rather than neutrality, the relative contributions of these two factors cannot be determined for these data.

Finally, the trend for the incongruent color word pairs is convex, as were the curves for the X's and nonwords, with peak response times for these Stroop stimuli occurring between the second and fourth grade equivalents for reading comprehension. The incongruent color-word trend has a different orientation from the other curves: the mean response times for the incongruent stimuli increase as reading comprehension increases from nonreaders to about the fourth grade level and then decreases only to its original level for the pre-sixth graders. In contrast, after the initial increase, the response times for the X's, nonwords, and congruent word conditions all subsequently decrease such that the response times for the pre-sixth grade group are substantially less than those for the nonreaders. This difference between the essentially zero-linear component for the Stroop condition and negative slope components for the other three curves is significant ($F = 52.92$, $p < .001$). The emergence in this study occurred with little reading skill development then continued to increase through several skill levels.

The most advanced young readers (1st-3rd graders reading at comprehension levels ≥ sixth grade equivalent) exhibit atypical response latencies when compared to the trends across reading comprehension established by the rest of the data. As can be seen in figure , this group of children responded more slowly than any other group. Their pattern of differences among response times as a function of stimulus condition is more like that of their age peers in the fourth grade equivalent group than like the pattern for the pre-sixth grade children, whose reading comprehension test scores are comparable.

We have no ready explanation of this slow color naming performance. While this highly advanced group responded more slowly in our Stroop task than their age peers, their oral reading rates were higher. Since the pattern of responding as a function of stimulus condition is so similar to that of fourth grade level readers, differences in automaticity do not seem to be involved. If the effect is shown to be reliable in future research, it may be worth investigating.

There was a significant interaction between response color and stimulus conditions. Responses to congruent color-word pairs, X's and nonwords are all slowest for green letters and fastest for red; however, responses to the green color are intermediate between the red and blue colors for the congruent pairs.

The most likely source of these color effects is differences in brightness of the three gels. Brighter colors are perceived slightly faster and may also have triggered the photo-transistor used to start the timer somewhat sooner than dimmer colors.

Since the interference effect is presumed to be due to response competition, then relative speeds of naming each color could well interact with stimulus condition. However, the effects are comparatively small and do not differ reliably as a function of reading comprehension level.

In summary, interference from all stimuli but the congruent words began to emerge during the early phases of reading skill development. Each stimulus condition, however, showed a course of development that differed from the others.

III. VISUAL SEARCH THROUGH SEQUENTIALLY PRESENTED LETTER STRINGS

James F. Juola
(Invited paper, Midwestern Psychological Association meeting,
Chicago, Illinois, May 5, 1979)

Three experiments were designed to study visual information processing abilities in tasks that mimic the visual experience of reading. All experiments were run using a Teleray CRT terminal driven by a PDP 11/03 minicomputer. The device allows us to present rapid, successive displays of letter strings to a common visual locus, thus having subjects view stimuli sequentially without necessitating eye movements. Previous studies using similar procedures have shown that the elimination of eye movements from search tasks can facilitate performance. For example, Lawrence (1971) had subjects search for a given category target in a list of sequentially presented words. He found that, at a presentation rate of 11 words per second, practiced subjects accurately detected the presence of the target about 75% of the time. Thus Lawrence demonstrated that, at a given level of accuracy, subjects could search through a sequentially presented list of words at about twice the rate reported by Neisser (Neisser & Beller, 1965; Neisser, Novick, and Lazar, 1963) using a similar procedure, but one that required eye movements as subjects scanned down a list of words. Similar experiments using normal text presented one word or one line at a time (e.g., Aaronson & Scarborough, 1977; Bouma & deVooge, 1974; Forster, 1970) have shown that reading under these conditions can occur at rates approximating those obtained when viewing text normally. The main goal of the present research program is to extend these efforts to a detailed study of reading for comprehension. The initial aim of our research is to determine the physical parameters of visual presentations that maximize reading ability; i.e., the number of letters of words visible at one time and the length of time each successive display is visible. The present paper is a report of some initial findings leading up to these goals.

Experiment I

The first experiment was an attempt to replicate, using the computer-driven display, some results that we have found several times using stimuli typed onto cards and presented in a tachistoscope. The main result that we have reliably found is that children and adults can determine whether or not a display contains a given target letter more rapidly if it is a familiar word than if if is an unfamiliar conbination of letters (Gilford & Juola, 1976; Juola, Schadler, Chabot, & McCaughey, 1978; McNamara, Ward, & Juola, 1978). Letter search times have also been shown to depend on the structure of the nonwords used, as we have found faster search times for regularly-spelled and pronounceable pseudowords than for irregular, unpronounceable nonwords. Since performance levels have been found to differ systematically among these three types of displays, we have proposed that letter strings can be recognized most efficiently as single units if they are words, as letter clusters or spelling patterns if they are pseudowords, and as individual letters if they are irregular nonwords (Taylor, Miller, and Juola, 1977). Word superiority effects in perception are presumably due to the fact that fewer units need to be isolated and categorized when recognizing words than other letter strings.

These hypotheses were tested in the first experiment using a letter search task. The stimuli were 30 common words at each of four length conditions: three, four, five, and six letters. These 120 words were used to make an equal number of pronounceable pseudoword anagrams and unpronounceable nonword anagrams. The orthographic regularity of the pseudowords and irregularity of the nonwords were confirmed by comparing their mean summed spatial digraph frequency counts determined from the Mayzner and Tresselt (1965) counts and from a more extensive sampling provided by Glen Taylor (personal communication). The mean digraph frequencies were slightly higher for pseudowords than for the words, and both exceeded the nonword frequencies by an order of magnitude. In 44% of the pseudowords and 8% of the nonwords a single letter in the word anagram was changed to produce an acceptable regular or irregular form.

All 360 different stimulus displays were divided into four different balanced lists of 90 items each, and these were then reordered randomly. Within each list, items were randomly selected to serve on either positive or negative trials. On positive trials, a target letter was selected randomly. Within each list, items were randomly selected to serve on either positive or negative trials. On positive trials, a target letter was selected randomly from the set of display letters, and on negative trials, the target letter was selected from a set of non-display letters balanced in frequency with the set of all letters used in the words, pseudowords, and nonwords. Various combinations of two lists were used to make trial blocks to 180 trials each. Across subjects, all displays were used about equally often on positive and negative trials, and positives and negatives were balanced within cells of the design.

The letters were lowercase and appeared on the CRT screen as a combination of dots in a 7 x 9 dot matrix which measured about 2mm by 4mm. From a line-of-sight viewing distance of slightly less than one meter, a six-letter word subtended a horizontal visual angle of about 1.5 degrees.

The sequence of events occurring on each trial is shown in Figure 1. Each trial began with the presentation of a target letter for 1.0 sec followed by a masking field of overlapped Xs and Os for .5 sec. The mask extended one character space to the left and one character space to the right of the largest display used. The mask was replaced by the word, pseudoword, or nonword display for 250 msec, after which the mask reappeared. If the subject's response was correct, the next target letter appeared 1.75 sec after the response, and if the response was incorrect, the word "ERROR" appeared for 2.0 sec followed by the mask and then the next target letter.

In Experiment I and all studies reported here, we collected data from four experienced observers and also from a larger group of naive student volunteers. In the first study, 12 unpracticed subjects were run for 3 blocks of 180 trials each plus a number of practice trials in a single one-hour session, and the 4 practiced subjects participated in 15 blocks distributed over five hourly sessions on different days. The only significant difference that we observed in the data is that the practiced subjects produced response times averaging about 250 msec shorter than those for the

TRIAL SEQUENCE

Example stimuli	t	⊠⊠⊠⊠⊠⊠⊠⊠	heart	⊠⊠⊠⊠⊠⊠⊠⊠
Description	target 1000 msec	mask 500 msec	display* 50-300 msec	mask RT + 1750 msec**

*Displays included from 1 to 9 different letter strings presented sequentially to a common locus.

**If an incorrect response was made, it was immediately followed by the word "ERROR" for 2.0 sec and then the mask for 1750 msec.

Figure 1. Examples of stimuli and the sequence of events typical of Experiments I, II, and III.

unpracticed subjects. For this reason the data were combined as shown in the next two figures.

The second figure shows mean response times plotted against number of display letters for positive and negative responses separately. The data are from words, pseudowords, and nonwords conbined, and their are about 1800 observations per point in the plot. Also shown are the mean error rates. In general, the results replicated similar studies of letter search performance using horizontal displays of letters (e.g., Atkinson, Holmgren, and Juola, 1969; Townsend and Roos, 1973), with mean response times increasing as a linear function of the number of display letters and in a parallel fashion for positive and negative functions. The slopes of the best-fitting linear functions are about 23 msec per letter.

The third figure shows mean response times for words, pseudowords, and nonwords separately as functions of the number of display letters. At all display lengths, response times were consistently ordered, with words producing faster response times than pseudowords, which were in turn responded to faster than nonwords. The overall error rates showed the same trend, with percentage errors equalling 2.5, 2.7, and 3.7 for words, pseudowords, and nonwords, respectively.

In summary, the effects of display type, number of display letters, and response type were all additive in the response time data. This result is consistent with our earlier conjecture (Gilford & Juola, 1976) that display type affects an initial encoding stage of visual search performance. Words are encoded more efficiently than pseudowords because they can sometimes be processed as units, whereas pseudowords are best recognized as several separate spelling pattern units, and nonwords must usually be processed letter by letter. Once encoding is complete, however, the scanning process operates in an equivalent, efficient way for all three types of displays, and the data are generally consistent with Sternberg's (1966) serial and exhaustive scanning model. The results of Experiment I are thus in no way unusual and serve mainly to replicate previous findings that we have observed in tachistoscopic experiments.

Experiment II

The second experiment was designed to extend the search task to a situation more similar to the visual experience of reading. The same stimuli were used as in the first experiment, but they were grouped into lists of five items of the same type (words, pseudowords, or nonwords) and number of letters. On each trial, a single target letter was presented followed by a sequence of five displays presented at the rate of 100, 200 or 300 msec each. The target letter appeared once, in either the second, third, or fourth item in the sequence, or it appeared nowhere in the sequence. All conditions were presented in a random order in blocks of 72 trials each. Sixteen unpracticed subjects were run for six blocks each plus practice trials in a one-hour session, and four practiced subjects were run for a total of 15 blocks each, distributed over several days. In overall performance, the 16 unpracticed subjects scored 86% correct responses and the four practiced subjects scored 88%. There were no other differences observed in the two groups' data, so their data were combined and d's were

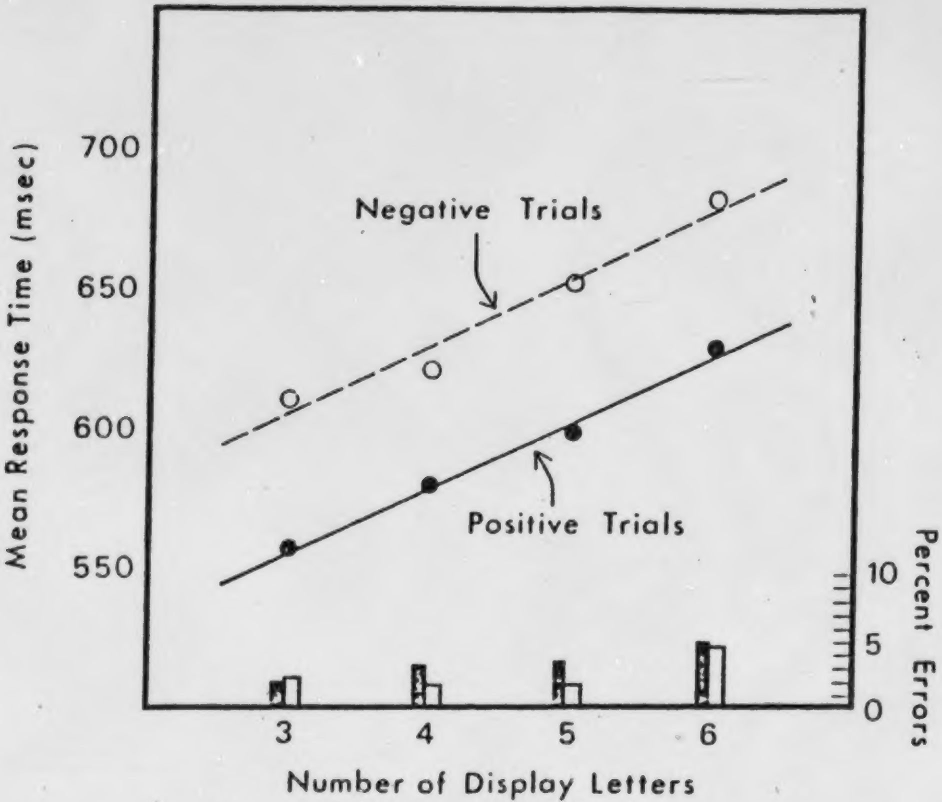


Figure 2. Mean response times plotted against number of display letters for positive and negative trials separately. Mean percent error rates are shown along the bottom.

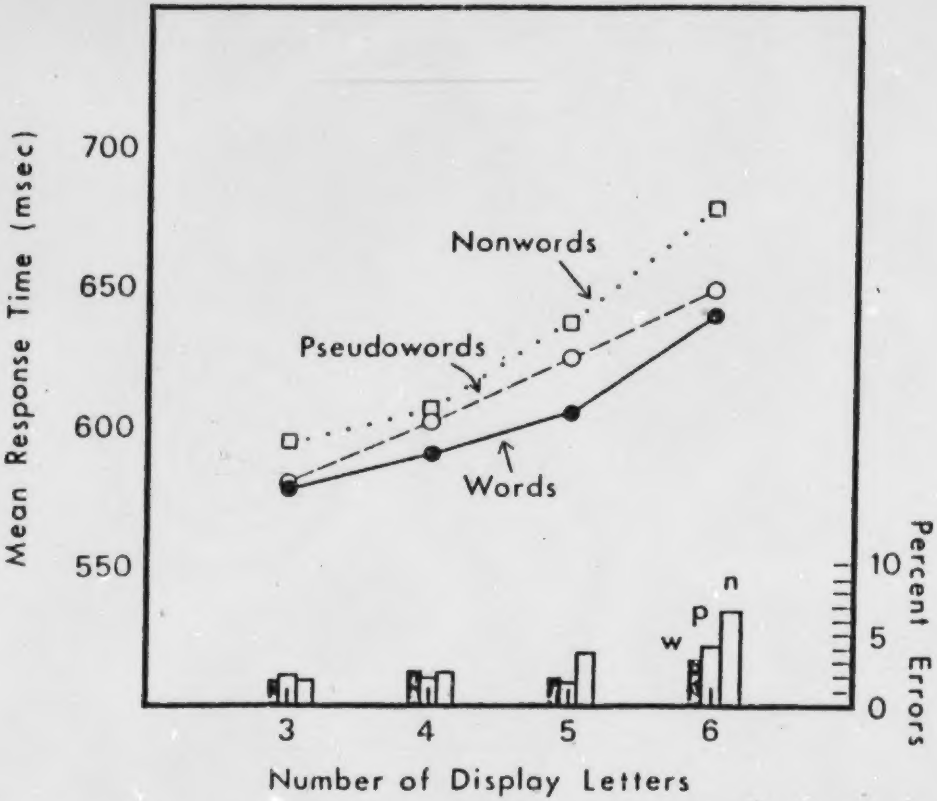


Figure 3. Mean response times for word, pseudoword, and nonword displays plotted against number of display letters. Mean percent error rates are shown along the bottom.

determined for each cell of the design based on individual subjects' and false alarm rates. The data plotting overall performance by display size and exposure duration are shown in Figure 4.

Figure 4 shows subject sensitivities expressed as d's which are based on mean performance levels of 78% correct at durations of 100 msec per item to 94% correct at durations of 300 msec per item. There are more than 900 observations per point represented in the figure. It is interesting to note that at the shortest durations, performance is effectively flat across stimulus display size, but for longer durations, performance is better for the shorter displays than the longer ones. It is as though, given greater processing time for the smaller displays, subjects are more adept at concentrating attentional capacity to a narrow focus, whereas fast presentation rates enable only an even distribution of attention over the general area occupied by the displays.

Figure 5 shows mean performance levels for strings of five consecutive words, pseudowords, or nonwords. The results replicate the findings of experiment I, showing better performance for words than nonwords at all duration levels. These data also replicate some findings reported recently by Krueger and Shapiro (1979). They used uppercase, six-letter words and irregular nonwords in a similar visual search task presenting nine successive displays per trial. As we did in Experiment II, they found a 4% difference between accuracy levels for words and nonwords over the same range of exposure durations.

Experiment III

The third experiment was designed to more closely approximate the visual experience of reading than Experiment II. Instead of manipulating redundancy within display items, between-item redundancy was manipulated by presenting strings of words that were either simple sentences or scrambled sentences. Forster (1970) has shown that subjects are more accurate in reporting words from six-word sentences than from scrambled sentences when the words are presented successively at a rate of 62.5 msec each, although only an average of about half the words could be reported. In earlier studies (Friedrich, Schadler, & Juola, 1979; McDermott, Miller, & Juola, 1979) we have shown that subjects could search texts for words and exemplars of semantic categories faster than meaningless subunits of words such as syllables or letters. Search rates through short paragraphs were slowed from about 200 words per minute to about 180 words per minute when the word order in the paragraphs was scrambled (McDermott, et al., 1979).

Expermient III used 120 different simple, nine-word sentences or scrambled rearrangements of the words in the sentences presented one word at a time at extremely rapid rates. The targets searched for were letters on half of the trials and any exemplar of a given semantic category, such as RELATIVE, FOOD or OCCUPATION, on the other half. Pilot work indicated that sentences presented at rates of 200 msec per word resulted in ceiling effects on performance when target detection accuracy was measured. Therefore, the words were presented at rates of 50 msec per word and 100 msec

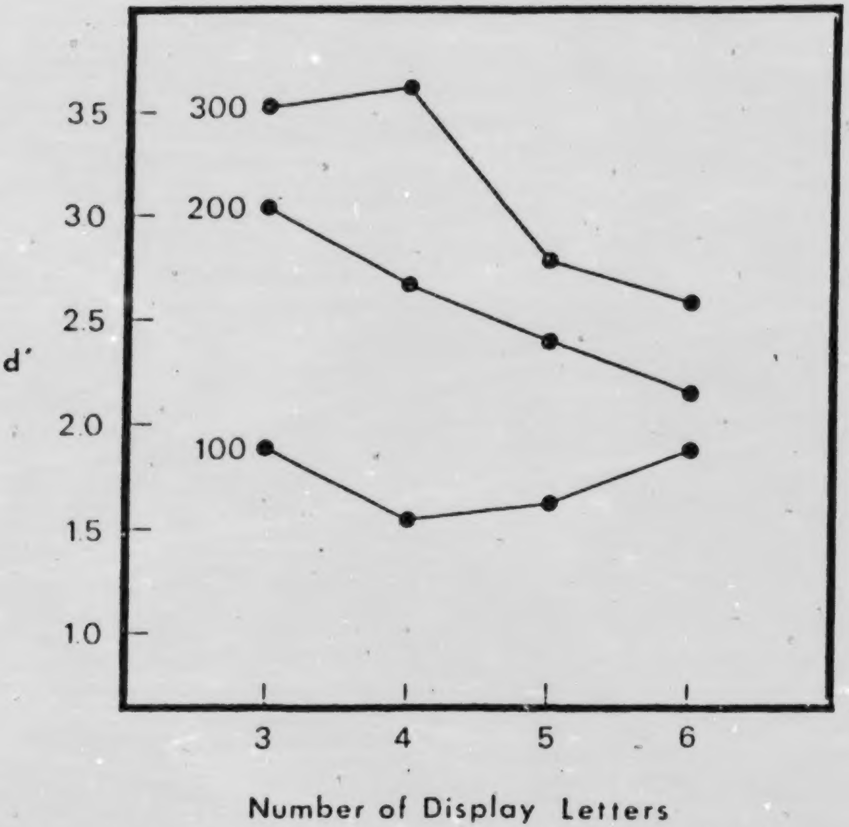


Figure 4. Mean target detection sensitivity (d') plotted against display size for five consecutive letter strings presented at the rate of 100, 200, or 300 msec each.

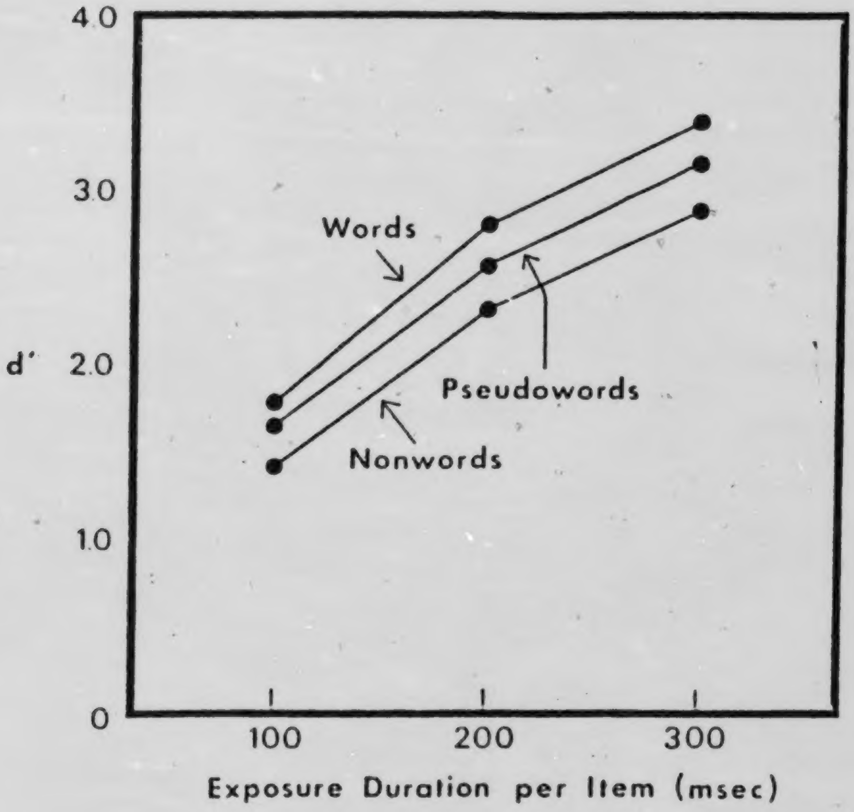


Figure 5. Mean target detection sensitivity (d') plotted against the exposure duration per item for lists of five consecutively-presented words, pseudowords, or nonwords.

per word, corresponding to reading rates of 1200 and 600 words per minute, respectively.

Eight inexperienced and four experienced subjects were each run for eight blocks of 72 trials each distributed over two days. The experienced subjects produced an overall target detection accuracy of 89% and the inexperienced subjects' mean accuracy was 88%. Since their data were similar in all important ways, they were combined, and the data for all 12 subjects are shown in Figure 6.

Here the data are presented for letter search in the left panel and category search in the right panel. The plots represent more than 900 observations per data point. The data show that the presence or absence of exemplars or semantic categories were detected more readily than specific letters at both the 50 msec per word rate and the 100 msec per word rate. Further, subjects were 2% more accurate for the normal, intact sentences than for the scrambled sentences. Performance in all cases was very good, given the extremely rapid rates of presentation, varying from 80% correct on letter trials presented at 50 msec per word to 95% correct on category trials at 100 msec per word.

General Discussion

The initial studies of this research program have demonstrated that subjects can process words presented at normal or greater than normal reading rates with high levels of accuracy. Further, this performance is sensitive to both within-word and between-word redundancies. The first two experiments showed that letters could be detected more accurately in common words than in regularly-spelled pseudowords and irregular nonwords. This effect was maintained when five consecutive items were presented at speeds equivalent to reading rates from 180 to 600 words per minute. Experiment III showed that both letters and category exemplars could be detected at high levels of accuracy in simple sentences presented at rates up to 1200 words per minute. It was interesting to find that any of several category exemplars could be detected more readily than a specific target letter (a result also reported by Friedrich, et al., 1979). Although reading has been characterized as "a search for meaning" (Haber & Hershenseon, 1973, p. 205), the advantage of cateogory search over letter search could be due to reasons other than that semantic information has priority to conscious processes over surface information while reading. For one example, the sentence "All the honey in the jar has been eaten," includes several references to the category FOOD besides the specific word "honey." In letter search there is only a single item in the sentence containing the evidence necessary for a positive decision, but there are generally several redundant sources of categorical information in the sentence. Of course it is just this sort of semantic redundancy, along with that of syntactive structures, that allows reading for comprehension to be accomplished efficiently. The importance of syntax is underscored in the results of Experiment III by the advantage that normal, intact sentences showed over scrambled sentences in both letter and category search.

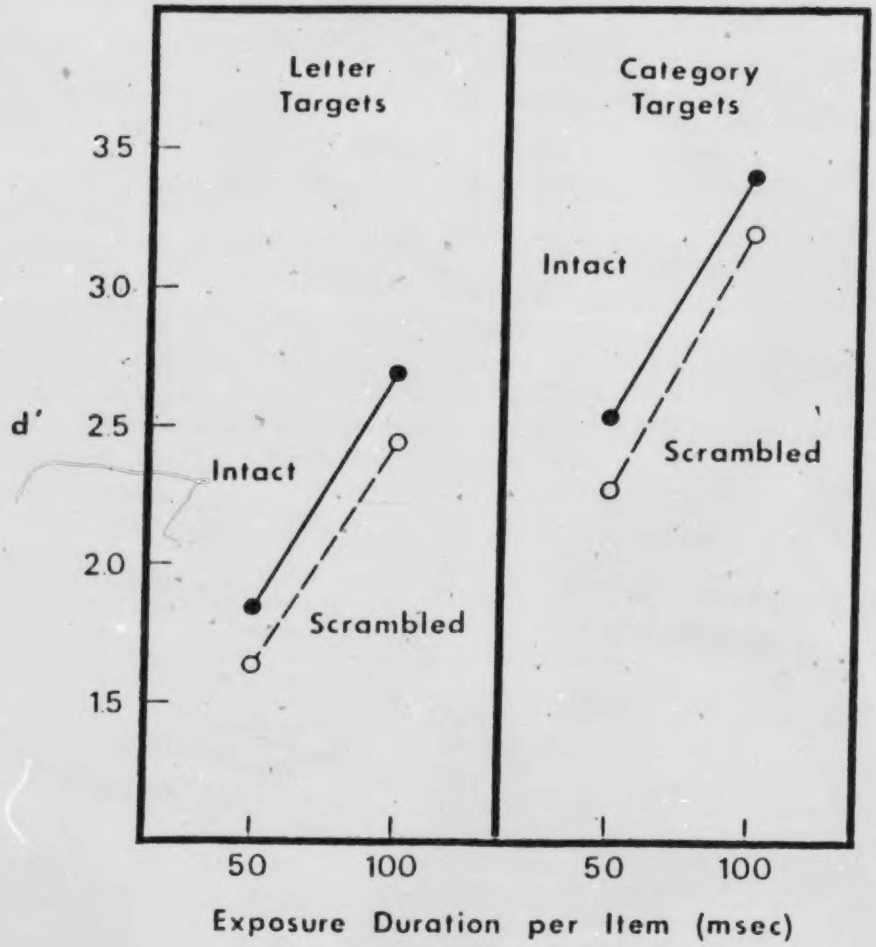


Figure 6. Mean target detection sensitivity (d') plotted against exposure duration per item for intact and scrambled nine-word sentences. The left panel shows the data for letter search, and the right panel shows the data for category search.

The experiments here are merely initial studies of the usefulness of computer driven displays for the study of reading. We are not beginning a series of experiments involving long passages of text that will be read both in normal, typewritten format and via computer presentation. Tradeoffs between reading speed and measures of comprehension will be examined using both procedures. The relevant parameters to be varied on the computer display will be the amount of text visible at any one time (varying from one word, to, perhaps, 50 character spaces) and the rate at which successive blocks of text are presented. The conditions will include simulations of normal visual experiences during reading; i.e., successive, but overlapping, windows of 10 - 20 characters and spaces presented every 200 msec. The goal will be to test the limits of reading efficiency in practiced subjects using the computerized procedure and to find the parameters of window size and presentation rate that maximize reading performance.

IV. SUMMARY AND CONCLUSIONS

Our research has been concentrated on the perception of single words and access of more abstract lexical codes and meanings in memory. We are continuing to work on the development of word recognition skills, particularly those involved in automatic processing of words. The automatization of rapid word processing is a necessary achievement for skilled reading comprehension, allowing processing capacity to be diverted from word recognition to understanding word meanings. We have found that word recognition skills develop rapidly as children learn to read, with most adult strategies and skills emerging by the second grade. Thus, it may be that the most important changes in children's reading abilities beyond the primary grades depend on the development of their abilities to comprehend what has been decoded from text.

The critical developmental changes that occur as a result of learning to recognize words rapidly may not depend as much on freeing processing capacity for allocation to other components of reading, but rather on how this allocation is made. Arriving at appropriate word meanings depends on use of context, and effective use of context relies on remembering previous information. Further, to get the gist of what is being read, the meanings of words currently being encoded must be integrated with earlier information to achieve a coherent structure of the entire passage. Thus, the speed with which words are recognized determines the potential efficacy of memory and integration processes, and word recognition speed may be critically important for comprehension ability. Working memory and other components of the human information processing system have temporal as well as "size" limitations. For some poor readers the major source of reading difficulty might be their very slow rate. Such readers may have to devote too much time and processing capacity to hold sufficient information in memory while they accumulate the necessary components to achieve integration. Perfetti and Lesgold (1980) have proposed a similar notion in their "bottleneck hypothesis."

Our work on the development of automatic processing suggests that speed of recognition continues to develop after automation occurs, a finding not evident in LaBerge and Samuels' (1974) seminal paper but emerging in the work of others (e.g., Ehri & Wilce, 1979). Such a sequence may have useful implications for instructional programs, so we will continue this phase or our investigation.

The need to investigate individual differences and to obtain longitudinal data in reading skill development is obvious. Reading is a highly complex, multiprocess skill; a number of processes said to be involved in reading have been identified. Within any group of readers, children or adults, performance on tasks measuring one or more of these processes varies widely. The relationships among such measures are relatively low, their relationship to standardized reading tests only moderate. The variation in these factors may stem from a variety of sources, and different children may have different problems. Alternatively, the same children may have different problems at different levels of reading skill, but we can only identify such relationships with repeated testing. We are not referring only to children with severe problems requiring special remedial instruction but to the larger group who perform below expectations. We have begun one longitudinal study on automatic processing skills and hope to develop others.

We are also beginning additional research on problems directly related to reading comprehension. This work will include studies of text presentation parameters, text structure, and their effects on reading speed and comprehension. Research using the CRT terminal will explore viewing conditions that maximize the readability of rapidly presented text. The visual extent of the display window and how rapidly successive windows are shown will be manipulated to find the optimal conditions. These will be related to theories of how successive units of text are integrated while reading for comprehension. Similar studies with children will explore the development of processes underlying comprehension. Other approaches that we are now using to study comprehension and its development include temporal analyses of oral reading and studies of anaphoric referencing and integration. These approaches to the study of reading make increasing use of normal reading tasks that are structured to provide analysis of reading processes in children and adults.

In sum, this paper bears the label of final report because it is the summary of work accomplished between January 1977 and 1979 when the extended research period for our first NIE grant ended. Substantial progress on information processing analysis of reading skills was made as should be evident from this report. Further, the work is being continued and expanded in new directions as we have briefly suggested here.

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Footnotes

1. Approximately 11% of the words had to be changed by a single letter in order to form an acceptable pseudoword or nonword anagram. The complete set of stumuli are listed in Juola et al., 1978.

2. Hand dominance was determined for the adults by asking them which hand they wrote with and for the children by observing which hand they used when asked to draw a face. For all participants, the yes button was assigned to the dominant hand and the no button to the non-dominant hand.

3. Before calculating the means and standard deviations shown in Table 1, outliers were removed from the data. Outliers were defined as any response time less than 250 msec for the adults and any less than 500 msec for the children as well as those response times in any cell for each participant that was greater than 1.7 times the mean of that cell with the potential outlier excluded. A total of 3.0% of all observations were excluded as outliers from the data presented in Table 1 and in all subsequent analyses.

4. Although departures from linearity in the children's data from the present study might preclude detailed analyses of linear parameters, it should be noted that the overwhelming evidence from visual search studies of this type is that response times and set size are linearly related (e.g., Atkinson, Holmgren, and Juola, 1969; Townsend and Roos, 1973). Further, the data from our earlier study (Juola, et al., 1978) show linear functions for kindergarten children and second grade students with approximately 2:1 negative-to-positive slope ratios for the younger children and 1:1 ratios for the second graders. While the present children's data are not as neatly fit by linear functions in a 2:1 ratio, they reflect the same pattern as the data from kindergarteners in our earlier study; i.e., response time functions diverge for negative and positive functions. This result presumably represents the use of a different search strategy than that of older children and adults who show parallel negative and positive functions.

Appendix A

The Development of Visual Information Processing Skills Related to Reading

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Literate adults can use their familiarity with specific words and their knowledge of English orthography to facilitate word recognition processes. The development of word superiority effects in visual perception was investigated in the present study using a search task with kindergarten (5.7 years old), second (8.0 years old), and fourth grade children (10.0 years old), and college students. The search task consisted of the visual presentation of a target letter followed by a three-, four-, or five-letter display. The target letter was included in the display on half the trials, and the displays were common words, orthographically regular pseudowords, and irregular nonwords. Although response times decreased with age, the three oldest groups showed similar effects for the size and structure of the displays. That is, response times increased linearly with the number of display letters, and responses were faster for word and pseudoword displays than for nonwords. The data for the kindergarten children showed evidence for the use of a different search strategy, and they did not respond differentially to the three types of displays. The results are discussed in terms of the implications for developmental models of visual search and word superiority effects in visual perception.

As children learn to read, they come to recognize an increasing number of words rapidly and, perhaps, holistically and automatically as well (Juola, Schadler, Chabot, McCaughey, & Wait, in press; LaBerge & Samuels,

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1974; Venezky & Massaro, in press). Many experiments have demonstrated that literate adults can use their knowledge of English orthography or their familiarity with specific words and common letter clusters to facilitate word recognition processes. Although word superiority effects in visual perception have not always been found, adults generally perceive words more accurately than other letter strings when they are briefly presented (Estes, 1975; Massaro, 1975; Reicher, 1969; Smith & Spoehr, 1974). Similarly, response times are usually shorter in visual search and same–different comparison tasks when words rather than nonword letter strings are displayed (Baron, in press; Henderson, 1977; Krueger, 1970, 1975).

The few studies with children have shown that word superiority effects in visual perception are found after only a few years' reading instruction. In one experiment, college students and fourth grade children searched for a given target letter in words and nonword letter strings. Search times were shorter for words than for nonwords and in the same proportion for the 9–10-year-olds as for the college students (Krueger, Keen, & Rublevich, 1974). Other experiments have indicated that children in the second and third grades are aware of structural regularities in English orthography, although it is not clear whether they are able to use this knowledge to facilitate visual perception (Doehring, 1976; Lefton & Spragins, 1974; Lefton, Spragins, & Byrnes, 1973). It is clear that, from the beginning years of reading instruction, children have some knowledge of English spelling patterns based on what they have read as well as on what they can intuit from known correspondences between phonology and orthography. Beginning readers' knowledge of orthography is undoubtedly more limited than that of older children and adults, however, and it may even be grossly inconsistent with standard spellings (Chomsky, in press; Read, 1971).

Of major interest for the present paper are the questions of what kind of orthographic information is acquired early in learning to read and how this knowledge comes to be used in reading and recognizing words. Specifically, we are concerned with investigating the development of rapid word recognition processes and other visual information processing skills presumably related to reading. We used a visual search task because reliable word superiority effects have been found in other studies using this method (e.g., Gilford & Juola, 1976; Krueger, 1970; Krueger et al., 1974), and because it seemed to be a task that could profitably be used with children who have not yet learned to read. The task consisted of the visual presentation of a single target letter followed by a three-, four-, or five-letter display. The subjects were instructed to make a positive response if the target letter were included in the display and a negative response otherwise. The displays were either common words, orthographically regular and pronounceable pseudowords, or orthographically irregular and unpronounceable nonwords. The subjects were kindergarten, second grade, and fourth grade children, and college students.

As would be consistent with the Krueger et al. (1974) results, we expected to find similar word superiority effects for college students and fourth grade children. Thus we expected both of these groups to show an advantage for words over nonwords. The pseudowords were included to give an indication of the basis of any word superiority effects obtained. If performance were similar for word and pseudoword displays, then the word superiority effect might not be due to any unique properties of words, but rather to more efficient processing of wordlike letter strings that obey rules of English orthography. On the other hand, an advantage for words over pseudowords would lend support to the idea that words can be processed as whole units, and thus they are recognized more efficiently than letter strings that must first be analyzed into their constituent units before recognition can occur.

The kindergarten children were included because they had very little if any reading experience and therefore would be unlikely to show any processing differences between words, pseudowords, and nonwords. Since a change in processing capabilities was expected between the kindergarten and fourth grade groups the performance of the second graders was of particular interest. If their performance were more like that of the kindergarten group, we would have evidence that the word superiority effect in visual perception depends upon more knowledge and experience than that acquired after less than 2 years of formal reading instruction. If, however, their performance were more like that of the older children and adults, it would indicate that the perceptual skills underlying word superiority effects develop rapidly as reading experience is gained. It is also possible that the pattern of results obtained among words, pseudowords, and nonwords could be unique for the second grade group. That is, if early reading experience results in the internalization and use of commonly-occurring spelling patterns, then words and pseudowords should show an advantage over nonwords at the same developmental level. Any additional advantage for words would depend on the use of whole-word units in the recognition process, which might not be possible until the fourth grade or later. On the other hand, if information about specific words is used in the recognition process before inferences based on more general orthographic rules are available, words could show a perceptual advantage over both pseudowords and nonwords for the second graders. Differences between pseudowords and nonwords could then become apparent only later, after a more significant amount of orthographic information has been acquired.

Systematically varying the number of display letters enables us to compare the visual search processes used by subjects in the different grade levels. Presumably, if the displays are processed in a serial, letter-by-letter fashion at some stage, response times should increase linearly with the number of display letters (Atkinson, Holmgren & Juola, 1969; Sternberg, 1966). The processing stages involved in visual search include, at least, display encoding, comparison of display and target information, response decision, and response execution. From the results of research using adult subjects, it has been argued that only the comparison stage in visual search is affected by the number of display letters, as long as these are small in number and presented foveally (Gilford & Juola, 1976). Thus, by applying the additive-factors logic of Sternberg (1969, 1975) we may be able to determine whether differences exist among words, pseudowords, and nonwords in perceptual encoding processes, subsequent comparison processes, or both. An adequate model of developmental changes in visual search performance should also be able to identify the stages involved in these changes and relate them to processes involved in reading.

METHOD

Subjects

The subjects were 20 college students, 20 fourth graders (mean age = 10.0 years), 20 second graders (mean age = 8.0 years), and 20 kindergarten children (mean age = 5.7 years). All subjects were native English speakers with normal or corrected to normal vision. The college students were enrolled in introductory psychology classes at the University of Kansas and participated in the experiment for course credit. The children were predominantly white middle- or lower-class students in Lawrence, Kansas schools and received $3.00 for their participation and as compensation for having to be transported to the University of Kansas campus.

Material and Apparatus

The stimulus set consisted of 30 three-letter words, 30 four-letter words, and 30 five-letter words selected from the Kučera and Francis (1967) word lists. The words had one syllable, no repeated letters, and were among those occurring with the highest frequency in the corpus of words upon which the lists were based (mean frequency of the stimulus words = 275/million). In addition, sets of pseudowords (pronounceable nonwords) and unpronounceable nonwords were constructed by making anagrams of the word stimuli. In approximately 11% of the cases, a single letter in the word had to be changed to make an acceptable pseudoword or nonword. The pronounceability of the pseudowords and unpronounceability of the nonwords were verified by five independent judges. Table 1 contains the complete stimulus set used in the experiment.

All stimuli were typed in lowercase letters using an IBM Selectric typewriter and Courier typeface. Before being placed on 15.2 cm by 22.9 cm white cards, the stimuli were photoenlarged (2×) so that they would approximate normal reading size when viewed in an Iconix three-field tachistoscope. All stimuli were .5 cm high. The lengths of the strings varied from 1.5 cm to 2.5 cm, depending on the number of letters, and these lengths corresponded to horizontal visual angles of from .88° to 1.46° when viewed in the tachistoscope.

Two different target letters were selected for each display string such that one matched one of the letters in the string and was used on positive trials, and the other did not match any of the letters in the string and was

TABLE 1

LIST OF STIMULUS MATERIALS USED IN THE VISUAL SEARCH EXPERIMENT

Words			Pseudowords			Nonwords		
act	best	board	tac	steb	droab	tca	tbes	rbdoa
air	born	break	ain	bron	kreab	arw	bnor	krbea
ask	both	chief	sak	thob	fiche	ksa	btoh	cfeih
big	come	claim	gib	moce	chaim	ibg	mcoe	lcmia
bit	fear	clear	tib	rafe	crale	itb	rfea	lraec
boy	game	earth	yob	meag	thare	ymb	gmea	htrae
car	girl	faith	rac	gril	thaif	rco	rlig	tfiah
cut	gone	field	tuc	noge	flide	ctu	ngeo	dleif
far	head	forms	raf	hade	morfs	rfa	hdea	sfmor
few	heat	great	wef	tane	trage	wfe	htea	rtaeg
gas	hour	heard	gos	bour	hearb	sga	hrou	rdhea
gun	just	horse	nug	pust	harse	ugn	jtus	hrsoe
hit	king	house	dit	gink	bouse	hti	ngki	hseou
hot	lead	large	oth	dael	grale	hto	dlea	rgeal
how	left	month	woh	flet	nomth	hwo	ftel	tnomh
job	line	night	pob	lein	ginth	bjo	lnei	tgihn
key	near	plant	yek	rane	glant	kse	nrea	tpaln
led	pain	quite	eld	naip	tique	lde	aipn	qteiu
low	rate	short	wol	taer	trosh	wlo	rtea	rsoht
men	rest	shown	nem	ster	whons	enm	rtes	nwohs
nor	rise	sight	orn	sier	thigs	nro	rsie	htigs
old	road	sound	lod	doar	douns	ldo	rdoa	dsuon
put	shot	south	tup	tosh	nouth	ptu	htos	htsuo
red	sort	speak	der	tors	skape	rde	otsr	ksaep
run	step	stage	nur	spet	geast	nru	tpes	gsaet
sat	take	think	tas	tade	thonk	tsa	tkea	tknih
sea	town	third	ase	nowt	drith	esa	nwot	hdtir
son	true	those	nos	rute	sothe	nso	uetr	htsoe
sun	turn	trade	nus	trun	drate	nsu	ntur	tdaer
two	west	young	wot	mest	yourg	wto	wtes	ngyou

used on negative trials. The positive letters were selected such that the target appeared approximately equally often in each serial position for each type of display. The combinations of target and display letters were further restricted to avoid presenting easily confusable letter pairs (e.g., *b* and *d*) as target and display items.

Procedure

The procedures for adult subjects and children were the same except for four modifications incorporated into the method for the children. These included (1) an initial 15-min training session for the children, whereas the adults read a set of instructions. (2) Adults', fourth, and second grade children were tested in two 60-min sessions, whereas the kindergarten children were tested in three 45-min sessions. (3) Two experimenters were present during the testing of each child; one operated the equipment and recorded the data while the other worked with the child. Only one experimenter was present for the adult subjects. (4) All children were given the oral reading part of the Wide Range Achievement Test (WRAT) after completion of the experiment.

Children's training procedure. The experiment began with the presentation of some sample stimulus cards in front of the subjects, rather than via the tachistoscope. Each child was shown a card with a single letter on it, a second card containing a pattern mask of three rows and ten columns of overlapped Xs and Os, then a third card with single letter. The child was told to remember the first letter and to say "yes" if the first and second letters were the same and "no" if they were different. This sequence was repeated until the subject achieved a criterion of five consecutive correct responses. The same procedure was then used while this child was looking through the viewport of the tachistoscope. In this phase, the child was told to respond "yes" by pushing a button with his dominant hand[1] and "no" by pressing another with his nondominant hand. After each child had reached the same criterion, cards containing practice letter strings of all the experimental stimulus types were used in place of the second, single-letter card. The child was told to press the yes button if the target letter was one of the letters in the display string and the no button otherwise. Practice trials again continued to criterion. Five kindergarten children failed to master the training task and were replaced.

Experimental task sequence. Each trial began with the subject looking into the viewport of the tachistoscope. The adults were given a verbal ready signal, and they initiated the trial by pushing a footswitch. The children were given the same ready signal, but the experimenter initiated the trial. Each trial consisted of a 1500-msec presentation of the target letter centered in the field of view, a 500-msec presentation of the pattern mask also centered in the viewing field, and the display string which remained on in the center of the field until the subject responded by pressing one of the buttons. The subjects were instructed to respond as rapidly as possible while being careful to avoid errors, and their response times were recorded from the onset of the display field until the appropriate response button was pressed.

Each session began with 18 practice trials using materials similar to the experimental stimuli. The 270 different experimental displays were presented once each to all subjects during the two or three sessions in one of two different random sequences. Further, the two target letters for every display were changed from one sequence to the other to insure that all displays were used equally often on positive and negative trials. Within each trial sequence, positive and negative trials occurred with equal frequency.

RESULTS

The response time data were submitted to a mixed-model analysis of variance in which there was one between-groups factor of grade (kindergarten, second grade, fourth grade, and college), and three within-groups factors of display type (words, pseudowords, and nonwords), display size (three, four, and five letters), and response type (positive and negative). There was a significant main effect of grade, $F(3,76) = 151.4$, $p < .001$, with response times decreasing as grade level increased. Response times increased with display size for all groups of subjects, $F(2,152) = 243.9$, $p < .001$, and positive responses were faster than negative responses, $F(1,76) = 66.1$, $p < .001$. The main effect of display type was also significant, $F(2,152) = 4.33$, $p < .025$. Multiple comparisons[2] indicated that words and pseudowords resulted in significantly faster responses than nonwords, $p < .05$, and that there was no overall difference between response times for word and pseudoword displays. Since the interaction involving display size, display type, and response type was not significant, mean response times for positive and negative trials were collapsed across display type for each grade level and are plotted as functions of display size in Fig. 1. Also shown in the figure are the best-fitting linear equations as determined by the method of least squares.

As shown in Fig. 1, the effect of display size decreased with age of the subjects, $F(6,152) = 64.3$, $p < .001$. Also, the younger subjects showed a greater difference in response times between negative and positive responses, $F(3,76) = 22.0$, $p < .001$. The significant interactions involving response type and display size, $F(2,152) = 21.3$, $p < .001$, and grade,

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[1] Hand dominance was determined for the children by observing which hand was used when they were asked to draw a face and for the adults by asking them which hand was dominant.

[2] The Tukey *B* procedure was used for all multiple comparisons at the level of significance reported in the text.

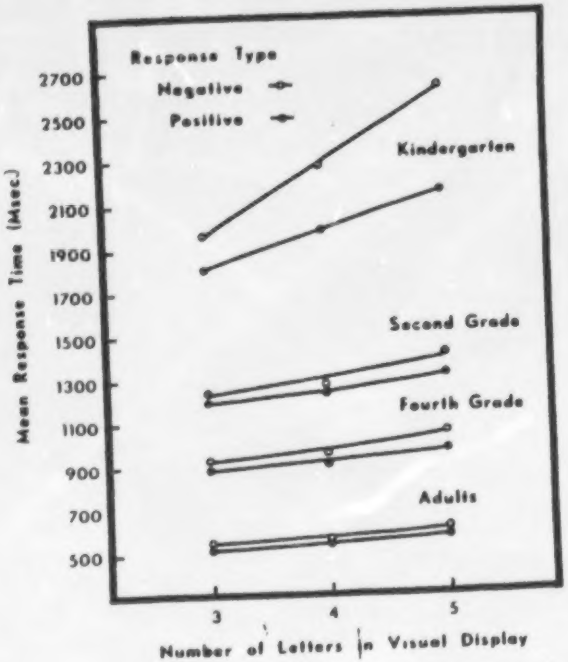

FIG. 1. Mean response times as functions of the number of display letters for positive and negative responses. The straight lines are least-squares fits to the data.

response type, and display size, $F(6,152) = 10.2$, $p < .001$, can be interpreted as reflecting similar effects of display size on positive and negative trials for the older subjects, whereas the slopes of the response time by set size functions for negative and positive trials are in a 2:1 ratio for the kindergarten children.

A final, marginally significant interaction in the overall response time analysis was found between display type and response type, $F(2,152) = 3.24$, $p < .05$. Multiple comparisons indicated that there were no significant differences among response times for words, pseudowords, and nonwords on positive trials. Thus the overall effect of display type seemed to be due to the significant difference between response times for word and pseudoword displays and those for nonword displays on negative trials, $p < .01$. This interpretation needs to be qualified, however, on the basis of further analyses performed on the response time data for each subject group separately. These are reported below, but it should be stated from the outset that the display type by response type interaction found in the overall analysis was not replicated in any of the individual grade level analyses.

Separate analyses of variance using a within-subjects design were performed on each subject group's response time data. The results of these analyses are reported in Table 2. For all grade levels there were significant main effects of response type and display size: responses were faster on positive than on negative trials, and response times increased with display size. The effects of display type were significant for the three oldest groups. Multiple comparisons made separately for each grade level indicated that there were no significant differences between response times for words and pseudowords for any group subjects. For college students, response times for words were significantly faster than those for nonwords, $p < .05$, with response times for pseudowords midway between them but not significantly different from either. For fourth and second graders, mean response times for both words and pseudowords were significantly faster than those for nonwords ($p < .01$ for fourth graders and $p < .05$ for second graders), but they were not significantly different from each other. For the kindergarten group there were no significant differences in response times among words, pseudowords, and nonwords. The mean response times for word, pseudoword, and nonword displays for each grade level are presented in Table 3.

The response type by display size interaction was highly significant for the kindergarten subjects, but only marginally significant for the fourth graders. This interaction was not significant for either the second graders or college student subjects. The negative slope was almost exactly twice the positive slope for the response time by display size functions for the kindergarten subjects, but the differences between the negative and positive slope values decreased with grade level such that the two slopes

TABLE 2

SUMMARY TABLE FOR ANALYSES OF VARIANCE COMPUTED SEPARATELY FOR EACH GRADE LEVEL

		Source of variance			
Grade level		Response type $df = (1,19)$	Display size $df = (2,38)$	Display type $df = (2,38)$	Response type × display size $df = (2,38)$
Kindergarten	F	36.0	107.4	< 1	16.6
	p	.001	.001	n.s.	.001
Second grade	F	9.8	62.9	7.5	2.28
	p	.01	.001	.005	.10
Fourth grade	F	45.9	56.5	10.4	4.2
	p	.001	.001	.001	.025
College	F	16.9	105.5	26.0	2.43
	p	.001	.001	.001	.10

TABLE 3

MEAN RESPONSE TIME IN MSEC FOR WORD, PSEUDOWORD, AND NONWORD DISPLAYS FOR EACH GRADE LEVEL

Grade level	Words	Pseudowords	Nonwords
	Display type		
Kindergarten	2128	2112	2104
Second grade	1258	1266	1301
Fourth grade	933	945	967
College	543	553	568

were approximately equal for the college students. The slope and intercept values for the functions fit to the data in Fig. 1 are presented in Table 4.

Table 5 presents mean response times on positive trials as functions of grade level and the serial position of the target letter in the display. These data are collapsed across display type since there were no significant interactions involving display type and serial position for any subject group. Separate analyses of variance were computed on the serial position data for each display size. For kindergarten subjects there were no reliable effects of serial position. For second graders and fourth graders there were significant main effects for four-letter displays, $F(3,57) = 4.92$, $p < .005$ (second graders) and $F(3,57) = 8.65$, $p < .001$ (fourth graders), and for five-letter displays, $F(4,76) = 3.01$, $p < .025$ (second graders) and $F(4,76) = 7.40$, $p < .001$ (fourth graders). For adults, there were significant main effects for three-letter displays, $F(2,38) = 5.67$, $p < .025$, four-letter displays, $F(3,57) = 8.01$, $p < .001$, and five-letter displays, $F(4,76) = 5.50$, $p < .001$. In general, response times increased with left-to-right changes in the serial position of the target letter, but this trend was offset by a decrease in response times for the rightmost serial position. Thus, positive response times were generally fastest when the target occupied one of the end positions, and they were slowest for the middle positions.

TABLE 4

SLOPES AND INTERCEPTS (IN MSEC) OF THE BEST-FITTING LINEAR FUNCTIONS RELATING POSITIVE AND NEGATIVE RESPONSE TIMES TO THE NUMBER OF DISPLAY LETTERS FOR EACH GRADE LEVEL

Grade level	Positive trials		Negative trials	
	Slope	Intercept	Slope	Intercept
Kindergarten	167.6	1289.4	334.2	932.1
Second grade	63.2	993.5	85.5	961.5
Fourth grade	37.0	770.4	56.5	752.1
College	24.7	442.1	28.1	457.2

TABLE 5

MEAN RESPONSE TIMES (IN MSEC) FOR POSITIVE RESPONSES AS FUNCTIONS OF THE LEFT-TO-RIGHT SERIAL POSITION OF THE TARGET LETTER IN THE DISPLAY FOR EACH GRADE LEVEL

Grade level	Three-letter displays			Four-letter displays				Five-letter displays				
	1	2	3	1	2	3	4	1	2	3	4	5
Kindergarten	1793	1877	1739	1827	1991	1955	2018	2035	2065	2117	2180	2092
Second	1168	1217	1181	1159	1223	1238	1307	1170	1320	1332	1355	1317
Fourth	[illegible]	892	889	829	917	944	929	875	976	991	1007	959
College	525	494	496	523	538	551	490	517	577	566	581	547

An analysis of variance similar to that performed on the overall response time data was also used for the arcsine-transformed error proportions. The analysis found significant main effects of grade $F(3,76) = 29.7$, $p < .001$, display size, $F(2,152) = 7.80$, $p < .001$, and response type, $F(1,76) = 33.2$, $p < .001$. In general, errors decreased with grade level, increased with display size, and occurred more frequently on positive trials than on negative trials. There were no significant interactions in the error analysis. The mean error proportions as functions of grade level, response type, display size, and display type are presented in Table 6. Since there were no significant effects of display type in the error data, it is not necessary to qualify differences in response times for words, pseudowords, and nonwords by considerations of speed-accuracy tradeoffs.

TABLE 6

MEAN PROPORTIONS OF ERRORS AS FUNCTIONS OF (1) DISPLAY SIZE AND (2) DISPLAY TYPE FOR EACH GRADE LEVEL FOR POSITIVE (+) AND NEGATIVE (−) TRIALS SEPARATELY

Grade level		Display size			Display type			
		Three letters	Four letters	Five letters	Words	Pseudo-words	Non-words	$\bar{X}$
Kindergarten	+	.092	.116	.132	.113	.115	.112	.113
	−	.075	.085	.092	.087	.083	.083	.084
Second	+	.055	.054	.094	.065	.074	.064	.068
	−	.041	.048	.050	.041	.046	.052	.046
Fourth	+	.036	.044	.038	.039	.049	.029	.039
	−	.029	.021	.027	.027	.025	.026	.026
College	+	.029	.033	.045	.037	.035	.036	.036
	−	.013	.021	.015	.018	.013	.018	.016
$\bar{X}$		.046	.053	.062	.053	.055	.053	.054

The mean score on the oral reading subtest of the WRAT was 1.6 for the kindergarten children indicating that they could name the letters of the alphabet and, on the average, pronounce the first 7–8 words from the WRAT word list. The second graders' mean score was 5.4, which corresponds to naming 41–42 of the words correctly, and the fourth grade children's mean score of 6.4 corresponds to 46–47 words. On a randomly selected sample of 30 words from the stimulus set, kindergarten children pronounced correctly an average of 1–2 words, the second graders pronounced 28–29, and the fourth graders had no difficulty pronouncing any of the words. The Lawrence public schools emphasize phonics in their reading program, and that emphasis seems to be reflected in the good pronunciation skills of the older groups. The children from the participating schools usually score in the average range on standardized reading tests.

DISCUSSION

College students, fourth grade, and second grade children apparently process visually presented letter strings in much the same way. Whereas response times decreased with grade level, the search process used by subjects in these groups appeared to be quite similar. They also were sensitive in similar ways to the types of materials being searched, as responses were generally faster for words and orthographically regular pseudowords than for irregular nonword letter strings. In contrast, the kindergarten children apparently used a different search strategy and were insensitive to manipulations of orthographic structure in the display. These two trends will be considered in more detail, beginning with an analysis of the visual search performance and followed with a discussion of the development of word superiority effects in visual perception.

Visual Search Performance

Visual search tasks similar to that used in the present experiment have yielded results much like those reported by Sternberg (1966) using a short-term memory search task (Chiang & Atkinson, 1976; Gilford & Juola, 1976; Townsend & Roos, 1973). It is not surprising, then, that the theoretical analysis of the processes involved in visual search should be of much the same form as the model proposed by Sternberg (1966, 1969, 1975) for memory search. This model consists of four processing stages that are assumed to be executed sequentially and independently between display onset and the terminal response. For the visual search task the stages include display encoding, comparison of the target with the encoded display items, response decision, and response execution.

In the first stage, the display items are assumed to be encoded into internal visual representations which can be compared with the target letter [illegible] experiment as well as those

display type differences is in the encoding stage, although the support for this hypothesis is indirect (see Gilford & Juola, 1976). Essentially, the argument is based on the fact that the display type effects do not interact with the effect of the number of letters in the display. That is, the slopes of the best-fitting linear functions relating mean response times to display size were equivalent for words, pseudowords, and nonwords, and only the intercepts differed for the various display types. Since encoding time is one component of the intercept of the response time by display size function, the interpretation of these results in terms of the model would place word, pseudoword, and nonword differences in the encoding stage. The slope of this function presumably represents comparison time only, and the results suggest that once encoding is complete, the subsequent comparison between the target letter and each display letter proceeds in a similar way for words, pseudowords, and nonwords.

The second stage of the model has been assumed to consist of comparisons between the target and each of the display items. Although parallel linear functions relating mean positive and negative response times to the number of display letters are consistent with the serial and exhaustive search model proposed by Sternberg (1966), they are also consistent with certain search models which allow for several display items to be compared with the target simultaneously (Atkinson, Holmgren, & Juola, 1969; Townsend, 1971, 1972, 1974). It is, therefore, impossible to describe the nature of the comparison process with certainty, although the data consistently show parallel positive and negative response time functions for adults with slopes on the order of 30 msec per display item (Atkinson et al., 1969; Gilford & Juola, 1976; Townsend & Roos, 1973), and the serial and exhaustive search model is a parsimonious way to account for these data.

The data for the older children, as shown in Fig. 1, are somewhat discrepant from the adults' data and from the predictions of the serial and exhaustive search model. There was a greater negative than positive slope for both the second and fourth grade children, although the effect was only marginally significant for the fourth graders and nonsignificant for the second graders. The differences in the positive and negative slopes are modest enough to infer that the second and fourth grade children generally used the same search strategy as the college students, but with less consistency. More importantly, display type did not interact with display size, suggesting that the slope differences were not due to differences in the use of orthographic structure in the displays but rather to the unstable nature of the childrens' developing search strategy.

For the kindergarten children the difference between the positive and negative slopes was large and clearly inconsistent with the exhaustive search model. In fact, the 2:1 ratio of negative to positive slopes shown in Fig. 1 is exactly what would be predicted if the search process were serial [illegible] rather than exhaustive. Since the display contained on until the subjects responded, it is also possible that the kindergarten children did not visually encode the entire display before initiating the comparison process as skilled readers have been presumed to do. Instead, they might have transformed each display letter into an auditory code and then tested it, in turn, against a comparable representation of the target letter. Search would then have terminated if a match were found, and it would have continued if the decision were negative. In essence, the kindergarten children might have completed the search process for one letter before encoding the next one. From our data we cannot distinguish between the strategies of letter-by-letter encoding and comparison versus encoding the entire display followed by a self-terminating search. However, the kindergarten children's very slow search rates are consistent with the use of auditory codes, and the experimenters frequently observed subvocalizations of the letters by the kindergarten children.

The discussion of serial, self-terminating and serial, exhaustive search models needs to be tempered by the results of the serial position analysis for positive trials (see Table 5). These data appear to be inconsistent with either model, since a left-to-right self-terminating search would produce linearly increasing serial position functions, and an exhaustive search would produce no significant serial position effects. The lack of significant effects in the kindergarten subjects' data can be reconciled with the serial, self-terminating model only be assuming that the order of scanning the display is inconsistent across subjects and/or trials. However, the presence of significant serial position effects for the three older groups cannot be reconciled with the serial and exhaustive search model suggested by the data shown in Fig. 1. That is, if the equivalent slopes of the display size functions are taken to indicate an exhaustive search, then the location of the target in the display should have no effect on positive response times. In contrast, we found both primacy and recency effects in the serial position data for adults and for the older children. These inconsistencies with simple serial search models lead to the conclusion that visual search performance should be characterized either by a parallel, self-terminating model or by a model which incorporates serial position effects into a processing stage rather than the letter comparison stage.[3] Several versions of such models

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[3] Two studies similar to the present experiment except for their exclusive use of adult subjects report serial position effects unlike those found here. Gilford and Juola (1976) found no significant serial position effects, and Lefton (1974) reports highly significant effects, with response times being fastest for extreme left positions in small displays and for left, right, and middle positions in large displays. A crucial factor appears to be the physical size of the display, as Gilford and Juola's display letters were about half the size of those used in the present study, and Lefton's were about twice the size. Serial position effects are apparently minimized if the entire display is presented within foveal vision. This is another argument in favor of localizing serial position effects in the encoding stage rather than in the comparison stage of processing.

have been investigated theoretically, but there are severe problems identifiability based on the data against which they are normally tested (se Townsend, 1972, 1974; Townsend & Roos, 1973). In summary, the seri and exhaustive search model fails to account for all of the data reported fo the older children and adults, but a serial, self-terminating model with a inconsistent scanning order can accommodate the kindergarten subject data.

The Word Superiority Effect

The second major finding of the present study concerns the nature of th word superiority effect in visual perception and its development in childre as they learn to read. In contrast with previous research (e.g., Gilford Juola, 1976; Juola, Leavitt, & Choe, 1974; Manelis, 1974) words did n lead to reliably faster or more accurate responses than did pseudowo displays, although an advantage over nonwords was found for the thr oldest subject groups. Gilford and Juola (1976) did find an advantage f words over pseudowords using adult subjects, the same visual search tas and materials and procedures similar to those used in the present stud The apparent discrepancy between the results of these two studies could due to the fact that word displays occurred on just one-third of the trials the present study versus one-half in Gilford and Juola's experiment. Th is, it is possible that our present subjects were less likely to expect wor and, therefore, adopted a different processing strategy from that used wh words occurred more often.

The present lack of word–pseudoword differences is consistent with t possible perceptual processes: (1) The displays are recognized on the ba of their individual letters, but inferences based on knowledge orthographic structure facilitate encoding words and regular pseudoword (2) The displays are recognized on the basis of familiar letter-cluster un when they are available, and these occur with about equal frequency words and pseudowords. In either case, the irregular nonwords must processed as strings of independent letters, thus leading to the failure inferential processes or higher-order unit matches and a consequent long encoding time before the comparison process can begin. A third possibili that words are recognized as wholes and are, therefore, processed m efficiently than the most wordlike of pseudowords, is not supported by t present data, although we believe that whole-word processing is a via perceptual strategy under some conditions (Juola, Leavitt, & Choe, 19 Taylor, Miller, & Juola, 1977).

A striking feature of the results is that whatever the basis of advanta for orthographically regular displays over irregular ones, it has develop by the middle of the second grade in a sample that cannot be described either gifted or educationally advantaged. Thus, we observed a facilitat ffect of orthographic regularity on visual search performance in children t about the same time that previous research has indicated that they are able to discriminate between orthographically regular and irregular letter strings (Golinkoff, Note 1; Rosinski & Wheeler, 1972). Although our task did not actually require the children to read the words, knowledge of English orthography apparently was applied early in the perceptual process to facilitate the encoding of regular letter strings. This skill enables the reader to process words more rapidly by limiting the necessity of identifying letters or decoding each word into pronounceable subunits and then blending these before recognition can occur.

The fact that there were no differences among the display types for kindergarten subjects is consistent with the hypothesis that they encoded and processed the display strings as individual letters. Beginning and prereaders presumably have little if any knowledge of standard orthography or familiarity with commonly occurring letter cluster units to use as a basis of word perception. That the shift in visual search strategy and the effects of orthographic regularity on perception should appear within the same grade level is not unexpected; familiarity with the visual language code gained through reading should logically facilitate both encoding and search processes. It is somewhat surprising, however, to observe the rapidity with which such familiarity is acquired, as demonstrated by the similar performance by second graders and adults. Although the rate at which visual information is processed continues to increase beyond the fourth grade, the cognitive processes involved in rapidly recognizing words and searching them for specific letters appear to be functionally equivalent for adults and for children who have been reading only about 2 years.

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Appendix B

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Visual search for letters in intact and mixed-case words and nonwords

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College students searched for single target letters in word and unpronounceable nonword displays of four, five, or six letters in length. The displays were typed in either intact upper- or lowercase form or in an alternating mixture of upper- and lowercase letters. Response times and error rates were less for words than for nonwords. Search rates, as measured by the slopes of the functions relating response time to display length, were greater for nonwords than for words. The search process apparently self-terminated for nonword displays, as the negative slope was about twice the positive slope. The positive and negative slope differences were less for words and were about equal for words in intact form. Case mixtures resulted in slower responses for words only, and this effect was apparently limited to encoding rather than to search or comparison processes. The relevance of these findings for similar results in same-different judgment tasks is discussed.

A common finding in the word recognition literature is that words are recognized more rapidly and accurately than strings of unrelated letters (e.g., Manelis, 1974; Reicher, 1969). This perceptual word-superiority effect could be due to differences in the way the letters in the strings are processed, since the orthographic redundancy in words could facilitate letter recognition processes (Massaro, 1975). Alternatively, the word advantage could be due to the use of higher order units, such as spelling patterns or even whole words, that are recognized more efficiently than are strings of independent letters.

One way to differentiate among these alternatives is to use displays that are presented in their normal visual form (either all uppercase or all lowercase letters) vs. displays that are altered in some way that preserves their orthographic structure (e.g., by mixing upper- and lowercase letters). If the use of orthographic redundancy is the key to word-superiority effects, word advantages over nonwords in perception should be the same for intact and mixed-case displays. In fact, same-different judgment times for simultaneously presented letter strings are slowed more for words than for nonwords when their letters are printed in mixed case relative to intact upper- or lowercase form (Bruder, 1978; Pollatsek, Well, & Schindler, 1975; Taylor, Miller, & Juola, 1977). Apparently, the mixing of letter cases in words disrupts the visual familiarity of multiletter units and increases the likelihood that they must be processed letter by letter, much as unfamiliar nonwords presumably are.

The problem for this explanation, and for the simultaneous matching task in general, is that it does not identify the processing stage or stages contributing to word advantages over nonwords. That is, word advantages could be due to the use of multiletter units during encoding or recognition of the words, but it is also possible that the presence of familiar units could facilitate later processing stages. In the simultaneous matching task, if one letter string is encoded before the other, the first must be held in memory in some form before it can be compared with the second. The comparison process itself involves encoded representations of both letter strings in memory. Both short-term retention and comparison processes could be facilitated by the use of familiar letter-cluster or whole-word units rather than individual letters. In fact, Bruder (1978) has argued that the word-superiority effect in the simultaneous matching task is due primarily to the use of familiar letter-cluster units to facilitate the comparison stage of processing, whereas Taylor et al. (1977) argued from similar data that at least part of the word advantage is due to encoding differences between words and nonwords.

From the results of earlier research (e.g., Juola, Leavitt, & Choe, 1974; Manelis, 1974), we believe that words can be encoded or recognized more efficiently than nonword letter strings due to the presence of familiar letter clusters that are processed as units. The present study was designed to provide converging evidence for the assertion made by Taylor et al. (1977) that mixing letter cases disrupts encoding processes for words and thereby reduces the word advantage in the same-different task. We used a visual search task in the present study in which a single target letter was given on each trial followed by a word or nonword display. The subject was to make a positive response if the target was in the display and a negative response otherwise. The displays were either intact (i.e., printed in all upper- or all lowercase letters) or mixed (i.e.,

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upper- and lowercase letters alternated within the strings). If the negative effect on word processing due to mixed letter cases is localized in recognition or encoding processes only, then there should be no interaction between the number of display letters and the intact vs. mixed-case variable. On the other hand, if the visual familiarity of the displays affects letter comparison time, then the slopes of the functions relating mean response times to number of letters should be steeper for mixed-case displays than for intact displays. The response times for nonwords should be unaffected by letter-case manipulations, as both encoding and comparison processes are assumed to be letter by letter in the absence of familiar letter clusters.

METHOD

The subjects were nine University of Kansas undergraduates who participated for course credit. Each subject participated in five 50-min sessions on separate days.

The stimuli consisted of 90 one- and two-syllable words and 90 nonwords, all four, five, or six letters in length. The words were selected from the Kučera and Francis (1967) word lists, with the constraints that they contain no repeated letters and that half (15) of the words at each length contain one syllable and the other half contain two syllables. The mean frequency of the selected words was about 490/million. The nonwords were constructed by making irregularly spelled and unpronounceable anagrams of the words.

All of the 180 stimuli were used once each in the three letter-case conditions: intact uppercase, intact lowercase, and mixed upper- and lowercase. The mixed-case displays were equally divided into strings beginning with upper- and lowercase letters, and letter cases alternated throughout the strings. Within each cell of the design, one-third of the stimuli were selected to be used on negative trials; that is, a target letter was randomly selected from those letters not included in the display. For intact displays, the targets were presented in the same (upper or lower) case as the display letters, and half of the targets were uppercase and half lowercase for the mixed displays. The other two-thirds of the stimuli were used on positive trials, with the targets selected approximately equally often from each serial position within all conditions. Further, about half of the positive target letters in each condition physically matched one of the display letters, whereas the other half matched a display letter in name only.

The stimuli were typed onto white paper using an IBM Selectric II typewriter. In order to minimize gross differences among the display types, a relatively large lowercase font (IBM Letter Gothic) and a relatively small uppercase font (IBM Prestige Elite) were used. The stimuli were then photo-enlarged to twice their normal size and individually adhered to 15.2 x 22.9 cm white cards for presentation in an Iconix three-field tachistoscope. From the subjects' point of view, a five-letter item subtended a vertical visual angle of about .3 deg and a horizontal angle of about 1.5 deg.

Each subject viewed all 540 experimental stimuli once each over the five sessions. The first session began with 24 practice trials, and Sessions 2-5 began with 15 practice trials using materials similar to the experimental stimuli. Each trial began with a ready signal from the experimenter. The subject initiated the trial by depressing a foot switch, illuminating the target letter for 1 sec in the center of the field of view. The target letter was immediately followed by a masking field containing a 4 by 9 grid of overlapped Xs and Os presented for 500 msec. The display followed the mask and remained in view until the subject responded by pressing one of two contact switches located under either hand. Both the assignment of positive and negative responses to the right- and left-hand switches and the sequence of experimental trials were randomly determined for each subject. The subjects were instructed to respond rapidly and accurately, and response times were recorded from the display onset until one of the response switches was pressed.

RESULTS

The results replicated similar measurements of search times for single-letter targets in horizontal strings of letters (e.g., Atkinson, Holmgren, & Juola, 1969; Chiang & Atkinson, 1976; Gilford & Juola, 1976; Juola, Schadler, Chabot, & McCaughey, 1978; Townsend & Roos, 1973). That is, mean response times increased linearly with the number of display letters, and responses were faster on positive trials than on negative trials. Response times were also shorter when the displays were words rather than nonwords. These results are shown in Figure 1, where mean correct response times are plotted against the number of display letters. In Figure 1, the data for intact upper- and lowercase displays are combined, since the small response time advantage for lowercase letters did not interact with any other factor.

Response times were about the same for intact and mixed-case nonwords (mean times were 631 and 637 msec, respectively), but mixing letter cases in words significantly hampered search performance, with mean times of 602 and 572 msec for mixed and intact words, respectively [$F(1,8) = 8.8$, $p < .025$, for the interaction of Word vs. Nonword by Intact vs. Mixed].

The other striking feature of the data shown in Figure 1 is the discrepancy in slopes, or the effects of

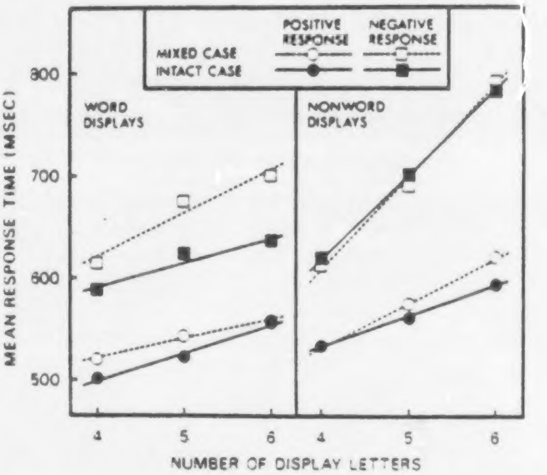

Figure 1. Mean response times plotted against the number of display letters for words (left panel) and nonwords (right panel). The straight lines are least-squares fits to the data for positive and negative responses to intact and mixed-case displays.

number of display letters on search times, for word and nonword displays. For words, the slopes averaged about 24 msec/letter on positive trials and about 33 msec/letter on negative trials, well within the range of those found in the studies cited above. The slopes for intact words on positive trials did not differ significantly from the slopes on negative trials [$t(8) = .45$, $p > .10$]. Slopes for mixed-case words also did not differ across response type [$t(8) = -1.24$, $p > .10$]. For nonwords, however, the slopes averaged about 37 msec/letter on positive trials and about 86 msec/letter on negative trials. The slopes for intact nonwords were significantly smaller on positive trials than on negative trials [$t(8) = -3.14$, $p < .02$], and the slopes for mixed-case nonwords were marginally smaller on positive trials [$t(8) = -1.91$, $p < .10$]. The interaction of display length and word vs. nonword was significant [$F(2,16) = 8.2$, $p < .005$], and the three-way interaction of these two factors with response type was marginally significant [$F(2,16) = 3.0$, $p < .10$].

Separate analyses of portions of the data revealed that there were no significant differences in response times to one- and two-syllable words, that positive responses were faster on physical-match than name-match trials, and that positive responses were somewhat faster for targets located in the leftmost serial position of the displays than in any other position.

An analysis of the error data revealed that more errors were made on nonword trials (about 4%) than on word trials (about 2%) [$F(1,8) = 12.9$, $p < .01$].

DISCUSSION

The results supported the hypothesis that mixed letter cases can disrupt word recognition processes by destroying the familiar units normally used in word perception. Word recognition seems to be more than a simple letter recognition and integration process, but rather depends on the familiar visual configurations of letter clusters found in common words. The lack of familiar letter clusters in the nonwords resulted in no processing differences between intact and mixed-case displays, a result consistent with letter-by-letter processing.

Although the present task is different from the simultaneous same-different task for pairs of letter strings, the results provide converging evidence for the Taylor et al. (1977) conjecture that familiarity affects encoding processes in the same-different task. Taylor et al. demonstrated a large overall word advantage and an effect of case mixtures on words but not on nonwords (see also Bruder, 1978). Both encoding and comparison processes are involved in the same-different judgment, however, and the task is not sufficiently analytic to separate the effects of visual familiarity on these two components of performance. In the letter search task used in the present study, recognition corresponds to an encoding process common to all displays, whereas comparison processes theoretically depend on the number of display letters. Since the effects of number of letters (the slopes in Figure 1) were independent of whether the displays were mixed or intact, it appears that the initial encoding process was affected by visual familiarity but that subsequent comparison processes were not (see also Gilford & Juola, 1976).

As a final note, it should be pointed out that the present results for the nonword displays are unusual in that the slopes for the negative response time functions are more than twice those of the positive functions. This result is more consistent with a serial self-terminating search than with an exhaustive search, which should produce equivalent slopes (Sternberg, 1966, 1975). Other studies using only intact displays and nonwords comparable to the present stimuli have consistently found nearly equivalent positive and negative slopes (e.g., Atkinson et al., 1969; Juola et al., 1978). The only novelties in the present study are the combination of mixed-case displays and the requirement to search for possible name as well as physical matches for the target. The presentation of unfamiliar nonword stimuli in these conditions could have resulted in a more cautious strategy on the part of the subjects, resulting in a slower search and a tendency to self-terminate the process as soon as a match was found. These speculations do little more than describe the data, but the evidence for a self-terminating search in tasks of the present type is scanty (but see Burrows & Murdock, 1969; Nickerson, 1966; Sternberg, Note 1), and attention should be called to the result when it is obtained.

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Developmental Changes in Units of Processing in Reading

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A visual search task was used to investigate the development of word processing skills used in reading meaningful prose. Children from the second and fourth grades and college students were asked to locate a prespecified letter, syllable, word, or category exemplar as they read through sentences. Target detection time, sentence reading time, and sentence comprehension were measured. The results provide converging evidence that whole words were the preferred units of processing during reading for all three grade levels. Reading rates for sentences in the word search condition were comparable to normal reading rates. The search for smaller units required additional processing time, but word and category search times differed only for the youngest subjects.

The structure of the written language is such that there is a great deal of redundancy in text; thus, a given word might be identified through the synthesis of featural information in its component letters or by prediction on the basis of semantic and syntactic constraints in the sentence. Lacking clear information of one form, others can be used to arrive at meaning.

One aspect of reading of particular interest to researchers is the unit of information used in the early stages of visual processing. Letters, spelling patterns, syllables, words, and phrases have all been suggested as potential processing units. In a review of relevant literature, Smith and Spoehr (1974) speculated that skilled readers employ a variety of strategies that can influence the size of the perceptual unit used. Others (e.g., Doehring, 1976; Gibson & Levin, 1975) have also proposed that reading is used for many different purposes and that the ability to handle units of various sizes is important for achieving these diverse goals. The nature of the task may thus determine the type of processing unit used (see also McNeill & Lindig, 1973).

Two factors stand out as particularly important in pursuing this line of inquiry. First, the reading process should be evaluated in a task that requires the subject to read meaningful prose for comprehension. Letter and word perception experiments, which constitute the bulk of previous research, have helped determine what skills the reader is capable of using under different task demands. However, these tasks cannot account for the effects of context and the attention to comprehension that characterize prose reading. Second, the developmental progression in the use of different processing units should be identified. Beginning readers might employ different types of information from skilled readers, and the ability to use larger units (e.g., words or phrases) might be dependent upon facility in using smaller units (letters or syllables).

There has been some work relevant to each of these points. In a series of experiments, Ball, Wood, and Smith (1975) had adults search for various targets through meaningful or scrambled text. The targets were words, syllables, and semantically defined items; in the first two experiments, using a between-subjects design, response times were fastest for locating the semantic targets in both meaningful and scrambled prose. The semantic-word search difference disappeared in a within-subject design (Experiment III). Juola, McDermott, and Miller (Note 1), used a similar visual search task and found that words were located most quickly, followed by semantic, then syllabic targets. Juola et al. concluded that the word is the primary unit of processing in reading prose, with the detection of semantic and syllabic targets requiring additional processing.

The task-dependent nature of the processing unit may account for the apparent discrepancy between these two results. There were a number of methodological differences that could have influenced the strategy used; for example, Ball et al. presented only positive trials, which may have had differential effects on the response criteria used for the targets. Presentation of the targets also differed; whereas Juola et al. (Note 1) presented a word target visually as a single unit, Ball et al. verbally specified the target, letter by letter. Ball et al. themselves suggest that this may have encouraged the use of a letter search strategy in that condition.

The developmental literature suggests that children can also use a variety of visual units, depending upon task demands, early in the acquisition of reading skills (see Doehring, 1976; Wanat, 1977). An indication of a developmental progression in the use of orthographic and lexical information can be found in two studies employing a visual search task (Juola, Schadler, Chabot, & McCaughey, 1978; McCaughey, Schadler, & Juola, Note 2). Children searching for a single letter in displays of words

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orthographically regular pseudowords, and irregular unpronounceable nonwords show knowledge of orthographic structure as early as second grade. The word advantage demonstrated by the pre-second grade children suggested to McCaughey et al. that the benefits of processing meaningful words emerge prior to benefits gained by knowledge of orthographic regularity. It is also interesting that, although response speed and accuracy improved with age, second- and fourth-grade children and adults appeared to search letter strings in much the same way.

The present study was designed to identify functional units that children use in reading meaningful text and to evaluate the relative difficulty of employing different types of units. A visual search task was used; subjects were asked to locate a prespecified letter, syllable, word, or semantically defined target as they read through sentences. The response times for locating the different targets should reflect the relative accessibility of these units during prose reading. Reading times and comprehension scores were obtained for comparisons across search conditions and with performance in a normal reading task.

METHOD

Subjects. The subjects were children who had recently completed the second and fourth grades and college students in an introductory psychology course. Eight male and twelve female college students received course credit for participation. The 20 second graders (13 male, 7 female) and 19 fourth graders (8 male, 11 female) each received $3.00 payment. The data for four additional children at each grade level were excluded due to equipment malfunctions. All subjects were native English speakers and had normal or corrected vision.

The children were students at a public school in Lawrence, Kansas and were from predominantly white, middle-class backgrounds. The Lippincott reading series, which is primarily a phonics approach, was the basis of the reading curriculum for both grades. The scores from the Stanford Reading Achievement Test, given 2 to 3 months prior to participation in this study, were available for 16 of the 20 second graders and all 19 fourth graders. The mean national grade equivalency ratings for the reading comprehension scores were 4.2 for the second grade and 6.6 for the fourth grade.

Apparatus and materials. The stimuli were presented by means of a Kodak Carousel slide projector and a ground-glass rear projection screen placed directly in front of the subject. A Wratten neutral-density filter (Kodak No. 96; N. D. .40) was placed on the front of the lens to reduce the intensity of the projected light without affecting the clarity of the stimuli. Two Hunter 120A timers were used to measure response times to the nearest millisecond.

The targets to be located and the sentences in which they were embedded were typed on white paper using an IBM Selectric typewriter with Courier typeface. These were photographed and made into slides. The target items included letters, syllables, words, and superordinate category labels. All targets except the category labels were typed in all upper case letters to prevent a direct physical match between targets and sentences. Category targets were defined by a phrase, e.g., "A Kind of Animal," to avoid confusion with the word targets. The syllable targets were either preceded, followed, or surrounded by hyphens to indicate their locations within the words.

Each sentence, typed on a single line, contained a key word in which the target was located. A pool of 75 key words was selected for second-grade comprehension on the basis of the norms and frequency counts established by Carroll, Davies, and Richmond (1971) and Harris and Jacobson (1972). All the words were nouns and were common exemplars of one of seven semantic categories: animals, foods, sports, occupations, clothes, relatives, and birds. Each key word had two or more syllables, at least one of which was neither a single letter nor a word in itself. Thus, an example of each target type was available for each key word.

On the basis of these key words, 150 nine-word sentences were generated. Information about appropriate sentence structures for second-grade readers was derived from Strictland (1962), who analyzed sentence structures in reading texts at all levels of elementary school. In keeping with her findings, the sentences generated for the present study were primarily of the simple subject–verb–object type with heavy use of verb modifiers and time and location modifying phrases. These sentences were screened by six second-grade children of average reading ability. Each child read the sentence aloud and indicated any difficult words or sentences. If more than one child was judged to have difficulty with a word it was replaced. In order to confirm knowledge of the categories, the children were asked to name some exemplars of each; they were able to do so quite easily.

The sentences were considered to have three segments (serial positions) of three words each. Each key word was used in different serial positions in two different sentences. Overall, there was an equal number of key words in each of the three serial positions. In addition, the sentences were constructed such that at least one letter and one syllable in the key word were unique in the sentence, and neither the key word's category label nor other exemplars occurred in the sentence.

In addition to the four search conditions there was also a normal reading condition. Sentences in this condition were preceded by the phrase "Normal Reading Sentence" which indicated that the sentence was to be read for comprehension but no search was required. Five sets of stimuli were generated so that all the sentences were used in all conditions. Each stimulus set was used by four subjects from each grade with the exception of one set that was used by only three fourth graders. All conditions were balanced for serial position; thus, in a given stimulus set, each condition had eight sentences with the key word in the first serial position, eight in the second serial position, and eight in the third.

Of these eight sentences in each serial position, six were randomly chosen to be used on positive trials and two on negative trials. The target for a negative trial was selected from the positive target pool. For the positive trials, there was only one possible word or category target for each key word. For both the letter and syllable searches, however, there was more than one potential target. The target letters and syllables were selected such that, within each serial position, the target occurred equally often in the first and last syllables of the key word. In addition, the target letters chosen were balanced, as far as possible, for the position within the syllable.

A comprehension question of the who, what, why, or where form was written for each sentence. The primary constraint in writing these questions was that the answer never be the key word, as attention to the target could focus the subject on the correct answer. Comprehension questions were asked after half of the sentences, randomly chosen within each set, with an equal number occurring in each condition.

Procedure. Second-grade children completed the testing in three 30-min sessions; the fourth graders used two 45-min sessions, and the adults participated in one session of approximately 1 hr. Before testing began, each subject was asked to write his/her name to determine hand dominance. All subjects received 30 practice trials and 120 test trials. Sentences from all conditions were mixed and presented in random order. The children received 10 additional practice trials to start the second and third sessions. Each trial consisted of the presentation of a target for 2 sec followed immediately by the presentation of the sentence. The presentation of the sentence was synchronized with the onset of the two timers, each of which could be stopped by pressing a telegraph key.

The subjects were instructed to read the sentence for comprehension at their normal reading speed. In addition, they were told to press a key immediately with the dominant hand if they saw the previously specified target as they read the sentence and to press a second key with the nondominant hand when they finished reading the sentence. Pressing the end-of-sentence key automatically terminated the display. Subjects kept their hands on the keys at all times to facilitate rapid responding and to prevent any interruption of the reading task. On the negative trials in which the specified target did not appear in the sentence, the subject made no response with the dominant hand and pressed the key with the nondominant hand as soon as the sentence was read.

The comprehension question was asked immediately after the sentence display was terminated; both the question and the response were given orally. Any errors, either in comprehension or in the search task, were pointed out after each trial.

RESULTS

Performance was evaluated on the basis of four different measures: (1) search time, the time needed to locate the target in the sentence, (2) reading time, the time needed to read the entire sentence, (3) search errors, and (4) comprehension scores.

Search Times

A 3 × 4 × 3 mixed-model analysis of variance was performed on the search times for positive trials to test the contributions of grade (second, fourth, college), target type (letter, syllable, word, category), and serial position of the target (first, second, third). The main effects for all three factors and the three first-order interactions were significant at $p < .001$; $F(2,56) = 73.2$ for grade, $F(3,168) = 54.4$ for target type, $F(2,112) = 181.5$ for serial position, $F(6,168) = 6.8$ for the Grade X Target Type interaction, $F(4,112) = 31.4$ for Grade X Serial Position, and $F(6,336) = 4.1$ for Target Type X Serial Position.

Mean search time was shortest for adults (1.32 sec), intermediate for the fourth graders (2.69 sec), and longest for the second graders (4.78 sec). The target type main effect reflects decreasing mean response times across the letter (3.36 sec), syllable (3.14 sec), category (2.84 sec), and word (2.38 sec) conditions. The serial position main effect was due to an increase in response time from 1.93 sec to 2.88 sec to 3.99 sec for the first, second, and third serial positions, respectively.

Figure 1 illustrates the Grade × Target Type interaction; mean search times for all three grade levels decreased across the letter, syllable, category, and word conditions, but the differences among target type conditions were greatest for the second graders and smallest for the adults. Simple main effects tests showed the target type differences to be significant at $p < .05$ for all grade levels. Pairwise comparisons were performed between the target type means within each grade level using a Tukey-B test at $\alpha = .05$. Only the letter–word comparison reached significance at the college level. All comparisons at the other two grade levels were significant except the category–word difference for the fourth graders and the letter–syllable difference for the second graders.

These results suggest that performance in the category condition showed greater improvement between the second and fourth grades than did that for the other targets. Performance for syllable search also improved at a faster rate than that for letter search, as indicated by the fact that the letter–syllable difference was not significant for the second grade but did reach significance for the fourth grade. However, detection time was still significantly shorter in the word search than in the syllable search at the fourth-grade level.

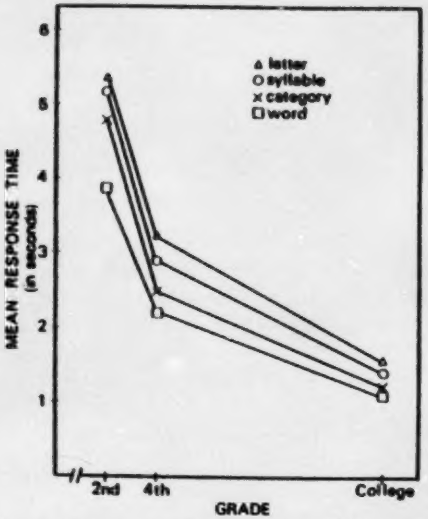

FIG. 1. Mean target detection response time as a function of grade and target type.

Within each grade level search times increased linearly across serial position, indicating that the sentences were searched at a steady rate. The Grade X Serial Position interaction resulted from the fact that the rate of search increased with grade level. The Target Type × Serial Position interaction reflected the slower search rates for the target types that produced longer overall response times; words showed the smallest response time increase across serial position, followed by category, syllable, and finally letter targets.

Reading Times

Reading times were determined for all sentences in the positive, negative, and normal reading conditions. On the positive trials, subjects responded to the location of the target in the sentence with the dominant hand and indicated completion of the sentence with the nondominant hand. The negative and normal reading trials involved only the latter response; therefore, the positive and negative trials were analyzed separately, using a 3 (Grade) × 4 (Target Type) mixed analysis for each. Mean response times are presented in Table 1.

Both analyses showed the same pattern of results found in the target detection times. The main effects of grade and target type and the Grade X Target Type interaction were significant at $p < .001$. Reading times decreased across letter, syllable, category, and word conditions; the interaction revealed that target type had more effect on the reading times for the second graders than for the adults. In the analysis of positive trials, $F(2,56) = 80.4$ for grade, $F(3,168) = 96.0$ for target type, and $F(6,168) = 12.7$ for Grade × Target Type. In the analysis of negative trials, $F(2,56) = 68.5$ for grade, $F(3,168) = 35.4$ for target type, and $F(6,168) = 3.9$ for the interaction.

TABLE 1

MEAN READING RESPONSE TIMES IN SECONDS*

	Grade		
Target type	Second	Fourth	College
	(A) Positive trials		
Letter	8.25(2.08)	4.54(1.67)	2.14(.47)
Syllable	7.79(2.05)	4.20(1.60)	1.99(.49)
Word	6.20(1.64)	3.33(1.16)	1.65(.41)
Category	6.98(1.91)	3.63(1.26)	1.78(.45)
	(B) Negative trials		
Letter	10.28(2.58)	5.37(2.47)	2.70(.82)
Syllable	9.19(3.81)	4.82(2.04)	2.42(.88)
Word	6.86(2.25)	3.47(1.50)	1.66(.44)
Category	7.27(2.63)	3.68(1.59)	1.85(.48)

* Values in parentheses are standard deviations.

The reading times are perhaps more meaningful if transformed into a reading rate of words per minute. The reading rates for sentences in all conditions were calculated, including a baseline rate for the sentences in the normal reading condition in which no search was required (see Table 2). The negative trials appear to mirror the trends of the positive trial data, but the times increase considerably in the letter and syllable conditions at the second-grade level. This is probably due to a tendency for the subjects to double-check a sentence before giving a negative response. The positive trials, therefore, should provide a more accurate estimate of reading rates.

We performed t tests on the positive trial data to compare the reading rate in the normal condition with those in the search conditions within each grade level. The reading rates in the word search condition were virtually identical to the normal rates in all grades; the rates in all the other conditions were significantly slower than the normal rate ($p < .001$) except in the category condition for the adults, which was borderline ($p < .057$). In order to evaluate the magnitude of these effects more clearly, disruption proportions were determined; that is, the proportion of change in reading rate relative to the normal reading rate was calculated for each target search condition. These values are presented in parentheses in Table 2. We then used t tests to evaluate the differences between the disruption proportions for the different grade levels within each condition; none of the tests approached significance. Thus, the relative change in

TABLE 2

MEAN READING RATE IN WORDS-PER-MINUTE FOR POSITIVE, NEGATIVE, AND NORMAL READING TRIALS[a]

		Grade					
		Second		Fourth		College	
Target type		Mean	Proportion[b]	Mean	Proportion	Mean	Proportion
Normal reading		96(30)		182(54)		351(126)	
Word							
Positive	(P)	93(23)	.01	177(49)	.02	352(118)	.01
Negative	(N)	87(30)		176(55)		350(110)	
Category	P	84(24)	.12	167(47)	.10	327(109)	.06
	N	84(30)		166(54)		314(102)	
Syllable	P	75(21)	.21	144(48)	.21	291(88)	.16
	N	67(24)		130(48)		250(84)	
Letter	P	70(19)	.25	132(39)	.27	267(78)	.22
	N	56(14)		119(44)		220(80)	

[a] Values in parentheses are standard deviations.

[b] Values in this column indicate the proportion of change in reading rate from the normal reading condition.

reading rate that occurred in a given search task was approximately equal for all grade levels.

Search Errors

Accuracy in the search task was determined for all grade levels, and overall error rates of 9.3, 6.4, and 2.5% were found for the second graders, fourth graders, and adults, respectively. The overall error rate includes two different types of errors: misses, when the subject failed to locate the target on positive trials, and false alarms, when the subject responded positively on negative trials. The two types of errors were analyzed separately.

A 3 × 4 × 3 (Grade × Target Type × Serial Position) mixed analysis of variance was performed on the arcsine-transformed error proportions of the misses. The mean error proportions are presented in Table 3. Significant factors included the main effects of grade, $F(2,56) = 15.0$, $p < .001$; target type, $F(3,168) = 13.6$, $p < .001$; and serial position, $F(2,112) = 3.4$, $p < .05$. The error proportions decreased with grade level and across the letter, syllable, category, and word target conditions. Error proportions also increased across serial positions. The increase was located primarily in the third serial position, as the mean miss rates for the first two positions were not significantly different (means = .056 and .057), whereas the rate for the third position differed from both (mean = .073).

TABLE 3

MEAN SEARCH ERROR PROPORTIONS FOR POSITIVE TRIALS (MISSES)[a]

	Grade			
Target type	Second	Fourth	College	$\bar{X}$
Letter	.113(.095)	.115(.058)	.050(.060)	.093
Syllable	.145(.135)	.062(.068)	.028(.074)	.078
Word	.047(.066)	.026(.029)	.000(.000)	.024
Category	.082(.064)	.054(.064)	.023(.044)	.053
$\bar{X}$	.097	.064	.025	

[a] Values in parentheses are standard deviations.

The Grade × Target Type interaction was the only significant interaction, $F(6,168) = 2.2$, $p < .05$, in the analysis of the misses: The second grade again showed the greatest differences among target type conditions. Simple main effects tests showed the target type differences to be significant for the second and the fourth graders ($p < .05$), but not for the adults. The interaction also reflects a difference between the second grade and the other groups in the order of the target type means. Whereas the fourth graders and adults made the most errors in the letter condition, the second-grade children made more errors when searching for syllables than for letters. Pairwise comparisons showed that only the syllable–word comparison was significant at the second-grade level and only the letter–word difference reached significance at the fourth-grade level.

A 3 × 4 (Grade × Target Type) mixed analysis was performed on the arcsine-transformed false alarm rates. Grade was the only significant factor, $F(2,56) = 5.3$, $p < .01$. The mean false alarm rate was 8.3% for the second graders, 6.4% for the fourth graders, and 2.3% for the adults.

Comprehension Scores

The mean error rates for the comprehension measure can be found in Table 4. The overall proportion of comprehension errors was 9.7% for

TABLE 4

MEAN COMPREHENSION ERROR PROPORTIONS FOR ALL TRIALS[a]

	Grade			
Target type	Second	Fourth	College	$\bar{X}$
Normal	.105(.089)	.050(.056)	.024(.065)	.060
Letter	.092(.100)	.053(.053)	.023(.045)	.056
Syllable	.129(.092)	.104(.106)	.025(.039)	.086
Word	.076(.074)	.049(.108)	.027(.045)	.050
Category	.085(.091)	.094(.101)	.013(.030)	.064

[a] Values in parentheses are standard deviations.

second graders, 7.0% for fourth graders, and 2.2% for adult subjects. Comprehension scores were available for all conditions, including the normal reading trials; therefore, a 3 × 5 (Grade × Target Type) mixed analysis of variance was performed on the arcsine-transformed error proportions.

The grade main effect, $F(2,56) = 12.3$, $p < .001$, showed that comprehension improved with grade level. Pairwise comparisons indicated that adult scores differed from those of the other two grades, but the second- and fourth-grade means were not significantly different. In the target type main effect, $F(4,224) = 2.4$, $p < .05$, the greatest proportion of errors occurred in the syllable condition, followed by the category, normal, letter, and word conditions, in that order. The mean of the syllable condition was found to be significantly different from each of the other means. The only other significant comparison showed that category search produced poorer comprehension scores than word search. The Grade X Target Type interaction was not significant.

Stanford Reading Test Scores

Recent Stanford Reading Test scores were available for all 19 of the fourth-grade children and for 16 of the 20 second-grade children. There were three subscores: vocabulary, word study skills, and comprehension. Pearson-r correlations between each of these three scores and the mean search response times for the four target type conditions were computed within each grade to help evaluate the relationship between the various search tasks and basic reading skills. In each grade, the only subtest that correlated significantly with the mean search times was the comprehension test. For the second graders, only the correlations of comprehension scores with syllable search time ($r = -.54$) and with word search time ($r = -.52$) reached significance ($p < .02$). All four search conditions were significantly correlated with comprehension in the fourth-grade group, with $r = -.56$ for letters, $r = -.70$ for syllables, $r = -.58$ for words, and $r = -.59$ for categories ($p < .001$).

The negative correlations indicate that the faster search times are accompanied by higher comprehension scores. The fact that the other reading subtests did not correlate reliably with search times suggests that the relationship between comprehension and search times is not simply due to general reading ability. Rather, search time is related to reading skills specific to comprehension of meaningful prose.

DISCUSSION

The search time, reading time, search error, and comprehension measures provided converging evidence that the preferred processing unit in reading single sentences is at least as large as the whole word. Word targets were located most quickly and accurately by all age groups. Perhaps even more compelling, performance in the word search and normal reading conditions did not differ from one another in either reading rate or comprehension. Thus it appears that word search and normal reading reflect much the same basic processes.

Of course, these results do not necessarily indicate that the word is the only possible functional unit in reading. McNeill and Lindig (1973) showed that minimum target detection time is not always a valid indicator of the basic unit used in speech perception. Using an auditory search task, they found that search was fastest when the target and the list to be searched contained the same-sized units. If their results also hold for visual search tasks, then the response times would vary as a function of the relationship between the size of the target and the material to be searched. Although search times might not be valid indicators of basic processing units used in all types of reading, they are still quite informative. Because baseline reading rates and comprehension measures were obtained, it is possible to evaluate the relative amount of disruption the different search tasks cause on the normal reading process. In addition, it is possible to identify developmental changes in the ability to carry out the additional processing.

Subjects at all three grade levels reduced their reading rate by the same proportionate amounts for the various search tasks, indicating that the children and adults employed similar strategies for maintaining comprehension while executing the search tasks. That is, in the non-word search conditions, reading rate was reduced a given amount to allow time for the additional processing necessary for identification of the particular target type. However, the skill with which this additional processing took place, as indicated by search times, *was* related to grade level; the differences among the search times for the four target types diminished as a function of grade.

Changes in the relative difficulty in locating the different targets should be indicative of a developmental progression in the acquisition of these processing skills. For the second graders, words were located faster than category members which were in turn found faster than syllables and letters. Between the second and fourth grades the search time for the category targets showed the greatest improvement. At the adult level, only the letter search was significantly slower than the word search.

The longer latencies for the category search than for the word search at the second-grade level suggest that processing must continue beyond basic word recognition in order to identify category membership. That superordinate category information was accessed more rapidly than letters and syllables indicates that less additional processing is necessary for semantic decisions about words than for analysis of their components.

The lack of reliable differences among the syllable, category, and word conditions at the college level could reflect a floor effect. The passages were short and designed for second grade comprehension; as a result, the task might not have been demanding enough to illuminate the relative difficulty in the search for different units for the adults. Some support for this argument can be found in the study by Juola et al. (Note 1). The pattern of results found by Juola et al. was the same as in the present study, but their adult subjects showed significant effects of target type as they read short, moderately complex paragraphs.

Both the comprehension and search error data suggest that the younger children have difficulty processing syllable units. The second graders showed a slightly different pattern of search errors from subjects in the other two grade levels. The second graders had the most misses in the syllable condition, whereas the miss error rates were highest in the letter condition for the fourth-grade and college students. The comprehension scores also showed a reversal of the usual trend; the proportion of errors in the syllable condition was significantly greater than the error rates in any of the other conditions. Although the Grade × Target Type interaction did not reach significance, the pattern of means in Table 4 shows that the second and fourth graders had particular difficulty with comprehension in the syllable search condition.

One reason for more comprehension errors in the syllable search condition could be that the children did not use syllables as single units. If so, they would have to hold a series of two to four letters in memory while reading the sentence. The word, letter, and category conditions presumably involve remembering a single item during the search. The additional memory load in the syllable search might be sufficient to reduce comprehension relative to the level maintained in the normal reading and other search conditions.

A relationship between syllable processing skills and comprehension is reflected in other data as well. In the present study, syllable search time was significantly correlated with the Stanford comprehension subtest scores at both the second- and fourth-grade levels. Perfetti and Hogaboam (1976) found that children with low comprehension scores have more difficulty with syllable decoding than do average readers. These correlations, however, may reflect a more general relationship between visual processing and comprehension. Rapid processing of visual information appears to aid comprehension by reducing demands on memory and allowing more time for inferential processes (Kleiman, 1975; Perfetti & Lesgold, in press). If syllable processing skills develop more slowly than whole word skills, as Doehring (1976) has also suggested, those children who can use syllable units efficiently are probably also processing words more rapidly. Note that in the present study, both word search times and syllable search times were significantly correlated with the standardized comprehension scores at the second grade level. Those children who scored well in comprehension were able to locate both words and syllables more rapidly than children who scored lower on the comprehension test.

In summary, all subjects identified word units in sentences more rapidly and accurately than syllable or letter units or category membership. Performance in the word search condition was in fact comparable to normal reading in terms of reading rate and comprehension. The children showed rapid improvement in the category search between the second and fourth grades. Performance in the syllable search condition also showed steady improvement; it is in this condition, however, that second-grade children appear to have particular difficulty. While there seem to be benefits of rapid syllabic processing, this skill is apparently not necessary in reading for comprehension. In fact, the skills involved in identifying a syllable unit within a word develop more slowly than the word or category processing skills. The demands of the particular reading task and the difficulty of the text no doubt affect reading processes and how available information is used. However, the evidence from the present study is that the functional unit of processing for both children and adults reading single sentences is at least as large as the whole word.

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Appendix D

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Memory search processes for words and pictures in elementary school children

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Children in the fourth and sixth grades searched memory sets of two, three, or four items for the presence of a given word or picture probe. The memory sets were all of one form on any trial, being either words or easily nameable pictures, and the probe form was varied to match or mismatch the form of the memory items. Subjects responded more rapidly when the probe form and memory set form matched, an effect that did not interact with the number of memory set items. Presumably, stimulus form effects are limited to encoding processes which precede comparisons between the probe and memory set items. The comparison process itself appears to be independent of the form in which the probe is presented.

The present study was designed to investigate stimulus encoding and memory comparison processes in children. Written words and their pictorial referents were used as stimuli in a Sternberg (1966) memory search task. The problem was to determine whether both encoding and comparison stages of the memory search process would be affected by the probe stimulus form. In a recent study using college students as subjects, Young and Juola (1977) demonstrated that stimulus encoding processes, but not subsequent comparison processes, were affected by the probe stimulus form. That is, the probes and memory set items were compared in some way that was apparently independent of whether or not their forms were the same. If similar results are obtained when children are used as subjects, it would indicate that they not only recognize stimulus equivalence at a conceptual level, but also can make comparisons between stimuli based on conceptual, rather than perceptual, information. If, however, the comparison process in children is based on perceptual aspects of the stimuli, then word and picture differences should exist at deeper levels of processing for children than for adults in short-term memory scanning.

METHOD

The subjects were 25 fourth-grade and 19 sixth-grade students selected randomly from class lists at Broken Arrow Elementary School, Lawrence, Kansas.

The stimuli consisted of slide transparencies containing single common typed nouns or photographs of easily nameable outline drawings selected from the set of items used by Young and Juola (1977). The stimuli included 72 pictures and 72 names of the same common objects. The words had a median frequency of occurrence in English of 9.7 occurrences per million words, as determined from the Carroll, Davies, and Richman (1971) counts for third- and fourth-grade reading material.

The subjects were run individually in three consecutive daily sessions. Each session included either 36 or 72 experimental trials preceded by 12 practice trials using materials similar to the experimental stimuli. All trials began with the serial presentation of a memory set of two, three, or four slides that were either all words or all pictures. These were presented at a fixed rate of 2 sec/slide, and the end of the memory set was signaled by the presentation of a blank red slide for 2 sec. This slide was followed by the onset of the probe stimulus, which was the same as one of the memory set items on half the trials. The probe form was varied over the three sessions such that the probes were always words on one day, pictures on another, and mixed pictures and words on the third day. The fixed probe form sessions were 36 trials in length and the mixed probe form sessions were 72 trials long. The order of the sessions over days was randomly determined for each subject. Within each session, the three levels of memory set size (two, three, or four items), the memory set forms (words or pictures), and the two response types required (positive if the probe was the same as one of the memory set items regardless of form and negative otherwise) were varied factorially. The order in which the trials were presented was random. On positive trials, the serial position within the memory set of the item matching the probe was also randomly determined.

A Kodak Carousel projector was used to present the stimuli on a 25 x 25 cm rear-projection screen, in front of which were mounted two telegraph keys 13 cm apart. Positive and negative responses were assigned to the two keys in a counterbalanced fashion, and the subjects were instructed to press the appropriate key as rapidly and accurately as possible in response to the probe stimulus.

RESULTS

The design was a factorial combination of the variables grade level (fourth or sixth), memory set size (two, three, or four items), memory set form (words or pictures), probe form expectancy (blocked or mixed), and response type (positive or negative). Separate analyses of variance were performed on the mean response times and the arc-sine-transformed error

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Table 1
Mean Response Times (in Milliseconds) and Error Proportions (in Parentheses) as Functions of Memory Set Size, Memory Set Form, and Response Type

Memory Set		Memory Set Size		
Form	Response	2	3	4
Words	No	968 (.053)	1004 (.052)	1082 (.065)
	Yes	960 (.111)	1045 (.088)	1045 (.091)
	$\bar{X}$	964 (.082)	1024 (.070)	1064 (.079)
Pictures	No	972 (.044)	1013 (.077)	1014 (.070)
	Yes	946 (.085)	1012 (.092)	1013 (.113)
	$\bar{X}$	959 (.065)	1012 (.085)	1014 (.092)

Table 2
Mean Response Times (in Milliseconds) and Error Proportions (in Parentheses) as Functions of Probe Form Expectancy (Blocked or Randomly Mixed), Probe Form, and Memory Set Form

	Blocked Probe Forms		Mixed Probe Forms	
Memory Set	Probe Form		Probe Form	
Form	W	P	W	P
Words	957 (.055)	1077 (.103)	984 (.056)	1044 (.092)
Pictures	1017 (.089)	950 (.071)	1027 (.100)	987 (.059)

proportions for each subject in all cells of the design.

In the response time analysis, significant main effects were found for memory set size $[F(2,86) = 36.4, p < .001]$ and memory set form $[F(1,43) = 7.85, p < .01]$. The nature of these effects can be seen in Table 1, which presents the mean response times and error proportions as functions of memory set size, memory set form, and response type. In general, the responses were faster for picture memory sets than for words, and response times increased with set size. Although the set size effect was smaller for picture memory sets than for words, this difference was not significant, and the effect of set size was to add about 36 msec to total response time for each additional memory set item.

Two significant interactions were found in the response time data: Probe Form by Memory Set Form $[F(1,42) = 78.2, p < .001]$ and Probe Form by Memory Set Form by Prove Form Expectancy $[F(1,42) = 8.61, p < .01]$. As shown in Table 2, responses were faster when memory sets and probes were of the same stimulus form than when the forms differed, and this effect was stronger in the blocked probe form sessions than in the mixed sessions. No other main effects or interactions were significant in the response time data.

A similar analysis of variance was performed on the arc-sine-transformed error data. The only significant main effect was response type $[F(1,42) = 18.5, p < .001]$, with more errors made on positive trials than on negative trials. As might be expected from the response time data, fewer errors were made when the memory sets and the probe stimuli were of the same form than when they differed $[F(1,42) = 19.1, p < .001]$. Finally, the interaction of Probe Form Expectancy by Memory Set Size was significant $[F(2,84) = 5.66, p < .01]$.

DISCUSSION

In general, the present results using fourth- and sixth-grade children replicated those obtained in a similar memory search experiment with adult subjects (Young & Juola, 1977). That is, although responses were faster and more accurate when the memory set and probe were of the same stimulus form than when the forms differed, this effect was constant with respect to memory set size. An interpretation of this result in terms of the additive-factors logic of Sternberg (1969) would be that stimulus form and memory set size affect different processing stages in children's memory search. A model consistent with this interpretation would presume that the presentation of words or pictures as memory set items biases the stimulus encoding mechanism to favor either verbal or pictorial inputs. Thus, probe stimuli that match the memory items in form are encoded more rapidly, even if a probe of a different form is expected, as in the fixed probe form sessions. Once the encoding process is complete, however, the comparison of probes and memory items is unaffected by the form of the stimuli. If we disallow the unlikely possibility that perceptual codes of pictures and words are compared at the same rate in short-term memory, we must assume that this comparison is based on more abstract, conceptual representations of the stimuli. Several experiments reported by Maisto and Baumeister (1975) provide justification for the use of the additive-factors logic in memory search tasks involving children; they also found that manipulations of probe stimulus form (intact vs degraded) affected encoding but not the comparison stage of processing.

In summary, children as young as those in our sample of fourth graders recognize conceptual equivalence between pictures and their names. This recognition of equivalence enables comparisons between encoded stimuli and remembered items to be based on conceptual rather than on perceptual codes. Although comparisons made at a deeper level of processing necessarily involve more complex stimulus encoding operations, these are apparently compensated for by more efficient processing of conceptual than perceptual information in memory.

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